İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

PRELIMINARY DESIGN OF THE SATELLITE MANAGEMENT SUBSYSTEM FOR A PROPOSED SUDANESE HIGH RESOLUTION EARTH OBSERVATION SATELLITE

M.Sc. Thesis by
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May 2015

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Date of submission : **04 May 2015**
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May 2015

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Teklif Edilmiş SUDAN Yüksek Çözünürlüklü Yer Gözlem Uydusu için Uydu Yönetim Sistemi Ön Tasarımı

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Mayis 2015

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FOREWORD

I would like to express my deep appreciation and thanks for my advisor who was guiding me during my graduate studies!

My thanks also go to my parents, Suad Elzaki and Mohamed Osman, who keep supporting, encouraging and loving me every second in my life!

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May 2015

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ABBREVIATIONS

ADCS	:	Attitude Determination and Control System
AOCS	:	Attitude and Orbital Control Systems
ASCII	:	American Standard Code For Information Interchange
BC	:	Bus Controller
BIL	:	Band Interleaved By Line
BIP	:	Band Interleaved By Pixel
BSQ	:	Band Sequential
C&DH	:	Command and Data Handling
CAN	:	Controller Area Network
CCD	:	Charge-Coupled Devices
CLCW	:	Telecommand Reception Status
COTS	:	Commercial off The Shelves
CPDU	:	Command Pulse Distribution Unit
CPU	:	Central Processing Unit
DC	:	Direct Current
DMA	:	Direct Memory Access
EDAC	:	Error Detection and Correction
EEPROM	:	Electrically Erasable Programmable Read-Only Memory
ESA	:	European Space Agency
GPS	:	Global Position System
GS	:	Ground Station
GSD	:	Ground Sampling Distance
HK	:	House-Keeping
HPC	:	High Priority Commands
HRC	:	High Resolution Camera
I/O	:	Input/Output
IFOV	:	Instantaneous Field of View
LEO	:	Low Earth Orbit
LTAN	:	Local Time Ascending Node

MS	**:**	Multi-Spectral
MSS	**:**	Multispectral Scanner
NAND	**:**	Negative-AND Gate
OBC	**:**	Onboard Computer
OBDH	**:**	On-Board Data Handling
OBSW	**:**	On-Board Software of A Satellite
PAN	**:**	Panchromatic
PCDU	**:**	Conversion and Distribution Unit
PCU	**:**	Power Conversion Unit
px	**:**	Pixel
RS	**:**	Remote Sensing
RT	**:**	Remote Terminals
RTU	**:**	Remote Terminal Unit
S/N	**:**	Signal To Noise Ratio
STK	**:**	Systems-Tool-Kit
SW	**:**	Software
TC	**:**	Telecommand
TDI	**:**	Transfer Delay and Integration
TDM	**:**	Time Division Multiplexing
TM	**:**	Telemetry

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PRELIMINARY DESIGN OF THE SATELLITE MANAGEMENT SUBSYSTEM FOR A PROPOSED SUDANESE EARTH HIGH RESOLUTION OBSERVATION SATELLITE

SUMMARY

For Sudan as a country newly started its local researches in the field of space science, aerospace and satellite engineering, a preliminary design of a remote sensing satellite is to be made. This thesis is focusing in the satellite management subsystem and the mission design.

In the beginning a review was done to the previous experiences in the field as a guide for the design, then the concept was surveyed, also the Remote Sensing basics and imaging process, the orbital dynamics and the management components and elements.

A satellite platform was chosen to serve the mission, all supporting subsystems' requirements are agreed to be satisfied. A general revision for the baseline design was done. This platform is considered to be a Chinese one because the opportunity to start this project with china is relatively high, and if the project is implemented, it is most likely to be launched by a Chinese satellite launch provider. The platform is mainly made for Remote Sensing projects and it has a heritage in space.

Then the mission design was started with naming the objectives and requirements for the satellite as all, from it the orbit parameters have been decided. Sensor specifications those can take the required high resolution images were selected. The operation modes have been determined to allow the calculations for the management subsystem. The satellite will be orbiting at an altitude of 650 kilometers in a polar sun-synchronous orbit. The satellite has to have the capability of taking two images per orbit. The images can be high resolution with narrow swath width or ten times low resolution with wider swath width.

The architecture of the management subsystem was defined based on the mission and previous experiences. Mainly the centralized design is used. The OBC specification was set and the onboard computer software's requirements were cleared. For simplifying the design a separate computer is dedicated for the attitude determination and control operations. Telecommand types are differentiated with the priority. The data management processes were unclouded, a calculations for the data size and type was done. This allowed the minimum storage size to be known. The compression is done for all images while the encryption is an optional process.

SpaceWire was picked out to be the internal bus because the high data rate needed when dealing with high resolution images taken by a high speed moving camera.

The final design conclude a satellite with 1m GSD (ground sample distance) resolution for panoramic and a 4m GSD resolution for multispectral channels which is orbiting 650 km polar sun-synchronized orbit. The onboard computer has 2 GHz clock with storage can save up to 128 Gbytes. 60 Gbytes can be downloaded every pass over the main ground station. The rest of memory will be used as a redundancy storage and as a storage for images those will be downloaded to other ground stations.

The main operation modes of the satellite are the acquisition mode, the battery charging mode, the recovery mode, the idle mode and the execution of a telecommand mode.

TEKLIF EDILMIŞ SUDAN YÜKSEK ÇÖZÜNÜRLÜKLÜ YER GÖZLEM UYDUSU IÇIN UYDU YÖNETIM SISTEMI ÖN TASARIMI

ÖZET

Astronomi 19. ve özellikle 20. yüzyılda baş döndürücü bir hızla ilerlemiştir. Teleskopların geliştirilmiş olması, spektroskopinin getirdiği imkanlar, evrenin genişleme içinde olduğunun farkına varılması, büyük patlama kuramı yoluyla kozmolojide meydana gelen gelişmeler ve diğer bilim dallarındaki gelişmelerin astronomiye katkıları bu bilimin ilerlemesine büyük katkılar sağlamıştır.

Bu gelişmelerin ardından devam eden süreçte, I. ve II. Dünya savaşını geride bırakıp 20.yy'ın üçüncü çeyreğinde soğuk savaş dönemine giren dünya aynı zamanda "uzay yarışı" diyebileceğimiz bir mücadeleye başlamıştır. Amerika Birleşik Devletleri ve Sovyet Sosyalist Cumhuriyetler Birliği arasında geçen bu mücadelenin astronomiye olan katkıları büyüktür. Uzaya uydu ve sonda yollayarak uzayı keşfetmek, insan göndermek, Ay'a insan indirmek gibi önemli olaylar bu dönemde gerçekleşmiştir.

Bu mücadeleden sonra uzayı keşfetme yarışı biraz olsun hızını kaybetsede, günümüzde insanoğlunu heyecanlandıran çalışmalar devam etmektedir. Avrupa Uzay Ajansı'nın en geç 2030 yılına kadar Mars'a insan göndermeyi amaçlayan Aurora programı bunlardan biri ve yarışı tekrar ateşleyebilir.

Uzay bilimleri, uzay teknolojileri ve uydu mühendislikleri alanında oldukça yeni bir ülke olan Sudan için bir uzaktan algılama uydusunun öntasarımının yapılması gereklidir. Uzaktan algılama, yeryüzünün ve yer kaynaklarının incelenmesinde onlarla fiziksel bağlantı kurmadan kaydetme ve inceleme tekniğidir. Yer ile herhangi bir temas olmaksızın yerin çeşitli özelliklerinin tespiti işidir. Uzaktan algılama kısa bir tanım yapılacak olursa, fiziksel temas olmadan cisimler hakkında bilgi almaktır. Bu tez de bahsedilen uydunun altsistemleri yönetimi ve görev tasarımına odaklanmıştır.

Başlangıç aşamasında tasarıma örnek olması için bu alandaki geçmiş çalışmalar incelenmiştir, Ardından konsept araştırması yapılmıştır. Ayrıca uzaktan algılamanın temelleri ve görüntü işleme, yörünge dinamikleri ve bileşen yönetimi üzerinde çalışılmıştır.

Görevin tüm isterlerini ve destekleyici altsistem gereksinimleri karşılayan bir uydu platformu seçilmiştir. Genel bir revizyon ile uydunun temel tasarımı belirlenmiştir. Çin ile birlikte çalışma olasığının yüksekliği ve uydunun tamamlanması halinde

fırlatmanın büyük ihtimalle Çin'li bir sağlayıcı tarafından gerçekleştirileceği göz önüne alınarak Çin'li bir platformda karar kılınmıştır. Uzay geçmişi bulunan ve uzaktan algılama projeleri için üretilmiş bir platformdur.

Görev tasarımı amaç ve gerekliliklerin tanımlanmasının ardından, yörünge parametrelerinin belirlenmesi ile başlamıştır. Gerekli çözünürlükte görüntü alabilecek algılayıcının özellikleri ve altsistem yönetim hesaplamalarının yapılabilmesi için çalışma modları belirlenmiştir.

Uydu 650 kilometre irtifada kutupsal güneş-senkronize yörüngeye sahiptir. Uydu bir yörünge dolanım süresi boyunca 2 görüntü alabilmelidir. Görüntüler dar bir alanı kapsayan yüksek çözünürlükte ya da on kat daha az çözünürlükte ancak daha geniş bir alanı kapsayacak şekilde olacaktır.

Altsistem yönetim mimarisi, görev ve geçmiş tecrübelere dayanarak tanımlanmıştır. Temel olarak merkezileştirilmiş tasarım kullanılmıştır. Uydu tümleşik bilgisayarı belirlenerek, yazılım gereksinimleri ortaya konulmuştur. Tasarımı basitleştimek adına yönelim belirleme ve kontrol altsistemi için ek bir tümleşik bilgisayar tasarlanmıştır. Telekomut türleri öncelikli olarak belirlenmiştir. Veri yönetimi, veri türleri ve veri büyüklükleri belirlenerek aydınlığa kavuşturulmuştur. Böylelikle minimum bellek büyüklüğü de ortaya çıkmıştır. Ayrıca bu doğrultuda tüm görüntü verileri sıkıştırılırken, istenildiği takdir de olarak şifreleme işlemi de gerçekleştirilebilmektedir.

İç veri yolu olarak SpaceWire seçilmiştir. Bu seçimde yüksek hızlı-hareketli kamera ile alınan yüksek çözünürlüklü görüntülerin yüksek veri iletim hızı gerektirmesidir. SpaceWire standart bir uzay aracı ağıdır. Avrupa Uzay Ajansı (ESA) tarafından yönetilen uluslararası bir projedir. SpaceWire elektrik akımı ile tahrikli sinyal veren iki çift kablodan oluşur, ayrıca bu kablolar arızaya ve gürültü sinyallerine karşı dirençlidir. Bu teknoloji komut ve kontrol fonksiyonları verilerini kombine eden masif veri transferi teknolojisi kullanmaktadır.

Tasarım, paranormik olarak 1m yer örnekleme yüksekliği (YÖY) çözünürlüğüne ve çokluspektral kanallar için 4m YÖY çözünürlüğüne sahip 650 km'de kutupsal güneş-senkronize yörüngedeki bir uydu olacak şekilde tamamlanmıştır. Tümleşik bilgisayar 2 GHz saat ve 128 Gbyte' a sahiptir. Uydunun yer istasyonu üzerinden her geçişi sırasında 60 Gbyte very indirilebilmektedir. Geri kalan bellek ise yedek amaçlı ve yer istasyonuna indirilmek üzere olan görüntü verisinin kayıt yeri olarak kullanılacaktır.

Uydunun temel çalışma modları veri alma modu, batarya şarj modu, geri kazanma modu, atıl mod ve telekomut modu olarak belirlenmiştir

Veri alım modu, 2 alt modda değerlendirilebilir; yüksek çözünürlüklü şerit modu ve geniş alan modu. Yüksek çözünürlüklü şerit modu, 8 km'lik alan genişliğine, PAN kanalında 1x1'lik alansal çözünürlüğüne sahiptir. Geniş alan modu ise 300 km alan genişliği ve 10x10'luk alansal çözünürlüğüne sahiptir.

Batarya şarj modu, uydunun yer istasyonu ile iletişim kurabilecek ve/veya görüntü dosyası için yeteli belleğin olmadığı ya da görüntünün zaman toleransına sahip olduğu durumlarda etkinleşerek düşük öncelikli sistemleri kapatır, güneş panellerini Güneş'e yönlendirecek komutu yönelim belirleme ve kontrol sistemine göndererek, maksimum enerji elde edilrek ve minimum enerji harcamanın yapılmasını amaçlar.

Geri kazanma modu, uydunun ciddi problemlerle karşılaştığı durumda sistemin kendini korumaya alarak kapattığı moddur. Atıl modda sistem yer ile uydu arasında herhangi bir iletişimin kurulmadığı ve görüntü alımının olmadığı ancak termal kontrolün tek etkin görevin olduğu durumdadır.

TC çalışma modu (veri alma modu) ise TC modulü yüksek öncelikli komutu alarak onu Komut Atım Dağıtımı Birimi'ne işlem görmesi için gönderir. Bu işlemin komutu görüntü alımını durdurarak, verinin yer istasyonuna gönderilmesini sağlar.

1. INTRODUCTION

From a general perspective, remote sensing satellite is acquiring and analyzing information about earth from distance. It has many types and technology. It is going to be the most useful tool in almost all the applications related to the earth studies. It is going to have main role in every other field of science.

As a developing country such as Sudan some people thought it is too early to think about owning a remote sensing satellite. This is totally wrong, and the opposite is absolutely true!

As a big country like Sudan with great unimproved resources. The RS satellite can be the best way to start managing these wealth and getting benefits.

The satellite engineering program for a country is a long way journey, the best first industrial step is an optical imagery satellite. The technology is available and it returns its cost in a good manner.

This thesis will make a general mission design and a design for the satellite management subsystem and its elements i.e. the OBC, data storage and buses.

1.1. Aim of The Thesis

- Design the mission parameters and the management subsystem of an earth observation satellite (SudaSat-1) which has a high resolution optical imager.

1.2. Methodology

The orbital mechanics will be used to design the orbit of the mission, then the operation modes, the type quality and quantities of the images will be set. The imaging sensor will be selected. All these data will be verified and fine-tuned by the Satellite-Tool-Kit (STK).

The management subsystem will be designed based on previous missions with near successful criteria and according to the special mission aspects. The data calculations will be performed because it is an important factor in designing the management subsystem.

1.3. Literature Review

At the end of 2010, optical space images with 1 m GSD or less are available from five countries (USA, Israel, India, Russia and South Korea) for civilian purposes. (Dowman, 2012)

Figure 1.1 gives an overview of the launch dates and GSDs of the panchromatic channels of the high resolution optical satellites.

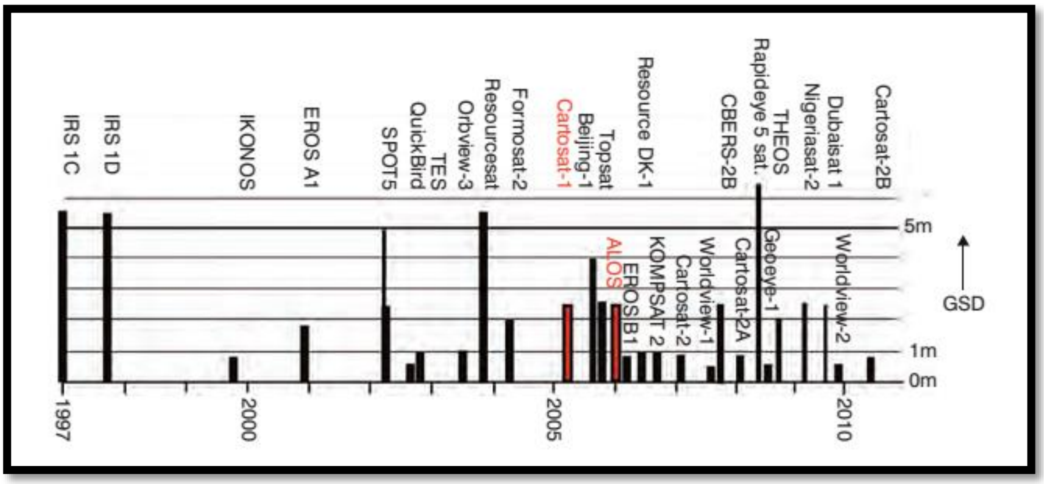

Figure 1.1: High resolution optical satellites launch date & GSD (Dowman 2012)

We will have an overview on the main characteristics for some of the high resolution satellites, orbit altitude, swath width, channels and resolution are mission design parameters, quantization and recording capacity are the management subsystem design parameters, and data rate is the communication design parameter.

The satellites whose characteristics are shown:

- IKONOS-2
- OrbView-3
- KOMPSAT-2
- WorldView-2

1.3.1. IKONOS-2 Satellite:

It is one of the very high resolution satellites working now, higher than our design. Its general characteristics are shown below. Figure 1.2 shows the satellite shape.

Figure 1.2: Ikonos-2 spacecraft and its sensor (Url-1)

- Altitude 681 km
- GSD 0.82 m and Multispectral 3.28 m
- Swath Width 11.3 km
- Channels: PAN and four band MS.
- Quantization: 11 bits
- On-board data recording capacity is 64 Gbit in solid-state memory
- Images download Data Rate of 320 Mbit/s
- Uplink of tasking and command data at 2 Kbit/s
- Downlink of housekeeping data and metadata at 32 Kbit/s
- Total instrument mass and power 171 kg, 350 W

1.3.2. OrbView-3

This satellite has the same resolution as our proposal. Figure 1.3 shows its integration and final assembly of the spacecraft. It has these characteristics:

- Altitude 470 km
- GSD 1 m - Multispectral 4 m
- Swath Width 8 km
- Channels: PAN and MS
- Quantization: 11 bits
- On-board storage capability of 32 Gbit.

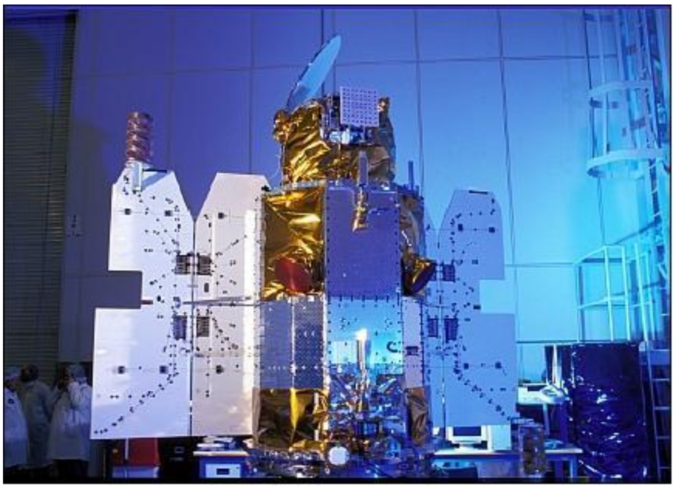

Figure 1.3: Integration and final assembly of the OrbView-3 spacecraft,
(Url-2)

1.3.3. KOMPSAT-2

This is another example of a satellite with the same resolution as ours. Figure 1.4 shows its configuration and Figure 1.5 shows its OBC. Then a list of its characteristics is written.

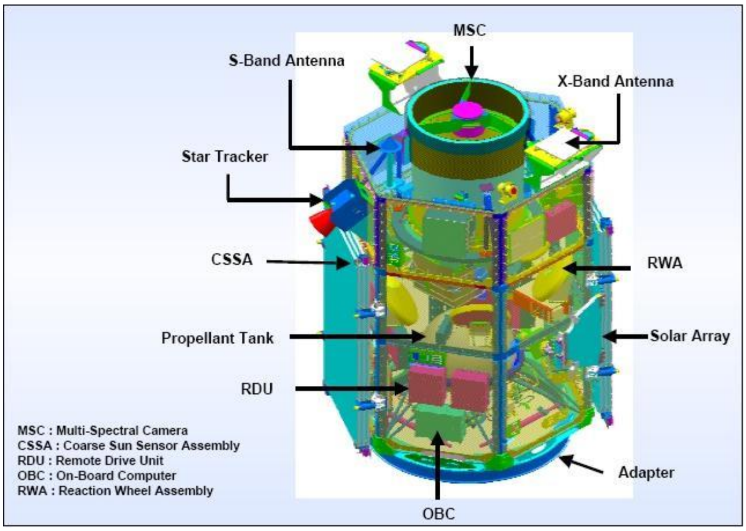

Figure 1.4: Configuration of the KOMPSAT-2 spacecraft
(Url-3)

- Altitude 685 km
- GSD 1 m - Multispectral 4 m
- Swath Width 15 km
- Channel: PAN & MS
- Quantization 10 bits

Figure 1.5: OBC of KOMPSAT-2, (Url-3)

1.3.4. WorldView-2

This is one of the most advanced and highest resolution satellites in the commercial Remote Sensing satellite. Figure 1.6 shows a view of the instrument and the spacecraft bus. Below some of its characteristics is listed.

- 0.46 m PAN and 1.84 m eight-band MS
- Launch mass   2,800 kg
- Power 3200 watts
- The command data: at 2 or 64 kbit/s.
- The housekeeping telemetry and tracking: at 4, 16, or 32 kbit/s of real-time data, or 524 kbit/s of stored data.
- The imagery: at 800 Mbit/s (dual polarization).
- The spacecraft provides a data storage capacity of 2.2 Tbit in solid state memory with EDAC.
- A total of 331 Gbit of imagery per orbit may be collected.
- In addition, real-time downlinks to customer sites are available using the same high-speed 800 Mbit/s.

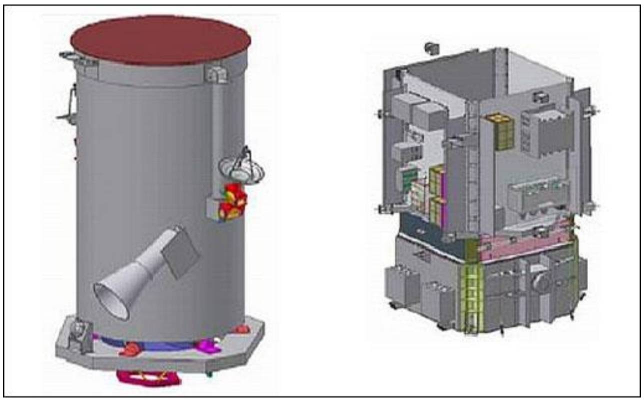

Figure 1.6: View of the instrument & the spacecraft bus image (Url-4)

1.4. Thesis Structure

In chapter two, a review of passive remote sensing satellites is presented, their general characteristics, payload types and imaging details are discussed.

In chapter three, the mission of SudaSat-1 has been designed, the requirements and orbital parameter, the resolution of the images, swath width and acquisition modes are predetermined. The sensor characteristics for the mission and the main ground station are chosen, the default data size and image dimensions are set.

In chapter four the satellite configuration and baseline design is discussed, the platform of the satellite is cleared and the other subsystems' assumptions are made.

In the fifth and last chapter, the satellite control and management subsystem is designed, the requirements are set, the architecture is proposed and the general aspects of the internal elements of the subsystem are discussed. The data size is calculated. The processor and storage types are selected. The system operation mode is named. Also in this chapter some scenarios and software flow charts are presented.

2. PASSIVE EARTH IMAGING SATELLITE TECHNOLOGY

Passive imaging methods relay in capturing the electromagnetic waves that coming from the sun and reflected by the Earth. The sun light is very important. The satellite can measure the light in many bands of frequencies according to the application.

2.1. Sun-Synchronous Orbit

This orbit type is suitable for passive imaging earth observation because of two factors, first the sun light always illuminates the satellite footprint. Second it allow the satellite's solar cells to harvest more power.

Also known as a helio-synchronous orbit, is one that lies in a plane that maintains a fixed angle with respect to the Earth–sun direction. In other words, the orbital plane has a fixed orientation with respect to the Earth–sun direction and the angle between the orbital plane and the Earth–sun line remains constant throughout the year. The satellite ensures coverage of the whole surface of the Earth.

2.2. Imaging Details

Pixels

A digital image comprises of a two dimensional array of individual picture elements called pixels arranged in columns and rows. Each pixel represents an area on the Earth's surface. A pixel has an intensity value and a location address in the two dimensional image.

Multilayer Image

Several types of measurement may be made from the ground area covered by a single pixel. Each type of measurement forms an image which carry some specific information about the area. By "stacking" these images from the same area together, a multilayer image is formed. Each component image is a layer in the multilayer image.

Panchromatic and Multispectral Image

In the Panchromatic image, the sensor is a single channel detector sensitive to radiation within a broad wavelength range. If the wavelength range coincide with the visible range, then the resulting image resembles a "black-and-white" photograph taken from space. The physical quantity being measured is the apparent brightness of the targets. The spectral information or "colour" of the targets is lost (Rajendran 2009).

In the multispectral image, the sensor is a multichannel detector with a few spectral bands. Each channel is sensitive to radiation within a narrow wavelength band. The resulting image is a multilayer image which contains both the brightness and spectral (colour) information of the targets being observed (Rajendran 2009).

Thus the multispectral image consists of a few image layers, each layer represents an image acquired at a particular wavelength band.

Spatial Resolution

Spatial resolution refers to the size of the smallest object that can be resolved on the ground. In a digital image, the resolution is limited by the pixel size, i.e. the smallest resolvable object cannot be smaller than the pixel size. The intrinsic resolution of an imaging system is determined primarily by the IFOV of the sensor. (Kumar, 2005)

2.3. Imaging Process

Before any image processing can commence an image must be captured by the satellite and converted into a manageable entity. This is the process known as image acquisition.

The image acquisition process consists of three steps; energy reflected from the area of interest, an optical system which focuses the energy and finally a sensor which measures the amount of energy.

2.4. Sensors

2.4.1. Sensor's Classification

The main payloads on board a remote sensing satellite system are sensors that measure the electromagnetic radiation emanating or reflected from a geometrically defined field on the surface of the Earth. Sensor systems on board a remote sensing satellite can be broadly classified as:

1. Passive sensors

A passive system generally consists of an array of sensors or detectors that record the amount of electromagnetic radiation reflected and/or emitted from the Earth's surface. We will discuss more about this type because it is the type of our satellite.

2. Active sensors.

An active system, on the other hand, emits electromagnetic radiation and measures the intensity of the return signal. Both passive and active sensors can be further classified as:

1. Scanning sensors

2. Non-scanning sensors

This mode of classification is based on whether the entire field to be imaged is explored in one shot as in the case of non-scanning sensors or is scanned sequentially with the complete image being a superposition of the individual images, as in the case of scanning sensors. All these types is shown in Figure 2.1 below.

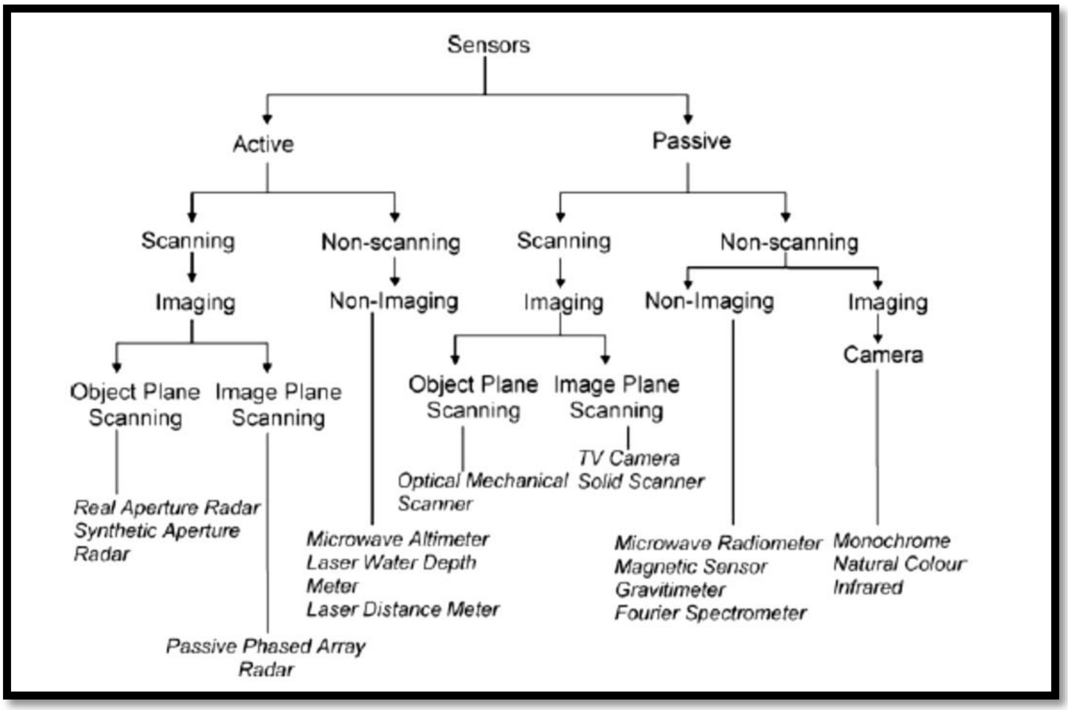

Figure 2.1: Various types of sensors on RS satellites, (Maini, 2011)

Scanning sensors have a narrow field of view and they scan a small area at any particular time. These sensors sweep over the terrain to build up and produce a two-dimensional image of the surface. Hence they take measurements in the instantaneous field-of-view (IFOV) as they move across the scan lines. The succession of scan lines is obtained due to the motion of the satellite along its orbit. It may be mentioned here that the surfaces are scanned sequentially due to the combination of the satellite movement as well as that of the scanner itself. Figure 2.2 illustrates the scanning and non-scanning sensors.

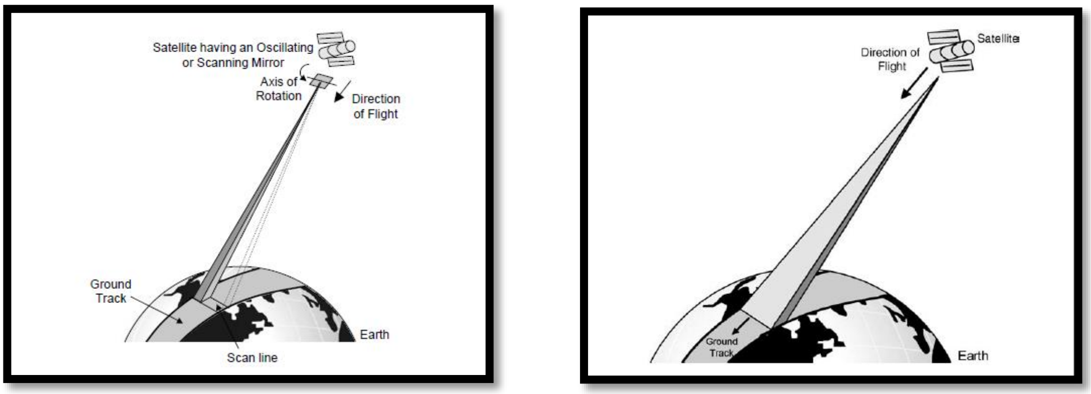

Figure 2.2: Scanning & non-scanning satellite RS system, (Maini, 2011)

2.4.2. Sensor's Parameters

Sensor parameters described in the following paragraphs include:

- Instantaneous field-of-view (IFOV)

This is defined as the solid angle from which the electromagnetic radiation measured by the sensor at a given point of time.

- Overall field-of-view

This corresponds to the total size of the geographical area selected for observation. In the case of non-scanning sensors, the instantaneous and the total field of-view are equal and coincide with one another, whereas for scanning sensors, the overall field-of-view is a whole number multiple of the instantaneous field-of-view.

- Signal-to-Noise ratio

This defines the minimum power level required by the sensor to identify an object in the presence of noise.

- Linearity

Linearity refers to the sensor's response to the varying levels of radiation intensity.

The linearity is generally specified in terms of the slope of the sensor's response curve and is referred to as 'gamma'. When the value of gamma is one, it means that the sensor has a linear response to radiation. A gamma that is less than one corresponds to a sensor compresses the dark end of the range, while a gamma greater than one compresses the bright end. Sensors based on solid state circuitry like CCDs are linear over a wide range as compared to other sensors.

- Wavelength band

Sensors employ three wavelength bands for remote sensing applications: the optical band, the thermal band and the microwave band.

- Swath width

The swath width of the sensor is the area on the surface of the Earth imaged by it.

- Dwell time

The sensor's dwell time is defined as the discrete amount of time required by it to generate a strong enough signal to be detected by the detector against the noise.

- Resolution

Resolution is defined as the ability of the entire remote sensing system (including the lens, antenna, display, exposure, processing, etc.) to render a sharply defined image.

Resolution of any remote sensing system is specified in terms of spectral resolution, radiometric resolution, spatial resolution and temporal resolution. These are described as follows:

(a) Spectral resolution: This is determined by the bandwidth of the electromagnetic radiation used during the process. The narrower the bandwidth used, the higher is the spectral resolution achieved. On the basis of the spectral resolution, the systems may be classified as panchromatic, multispectral and hyperspectral systems. Panchromatic systems use a single wavelength band with a large bandwidth, multispectral systems

use several narrow bandwidth bands having different wavelengths and hyperspectral systems take measurements in hundreds of very narrow bandwidth bands.

Hyperspectral systems are the ones that map the finest spectral characteristics of Earth.

(b) Radiometric resolution. Radiometric resolution refers to the smallest change in intensity level that can be detected by the sensing system. It is determined by the number of discrete quantization levels into which the signal is digitized. The larger the number of bits used for quantization, the better is the radiometric resolution of the system.

(c) Spatial resolution. Spatial resolution is defined as the minimum distance the two point features on the ground should have in order to be distinguished as separate objects. In other words, it refers to the size of the smallest object on the Earth's surface that can be resolved by the sensor. Spatial resolution depends upon the instantaneous field-of-view of the sensor and its distance from Earth. In terms of spatial resolution, the satellite imaging systems can be classified as: low resolution systems (1 km or more), medium resolution systems (100m to 1 km), high resolution systems (5m to 100 m) and very high resolution systems (5mor less). It should be mentioned here that higher resolution systems generally have smaller coverage areas.

(d) Temporal resolution. This is related to the repetitive coverage of the ground by the remote sensing system. It is specified as the number of days in which the satellite revisits a particular place again. Absolute temporal resolution of the satellite is equal to the time taken by the satellite to complete one orbital cycle. (The orbital cycle is the whole number of orbital revolutions that a satellite must describe in order to be flying once again over the same point on the Earth's surface in the same direction.)

However, because of some degree of overlap in the imaging swaths of adjacent orbits for most satellites and the increase in this overlap with increasing latitude, some areas of Earth tend to be re-imaged more frequently. Hence the temporal resolution depends on a variety of factors, including the satellite/sensor capabilities, the swath overlap and latitude.

Remote sensing satellites generally provide information either at the regional level or at the local area level. Regional level remote sensing satellite systems have a resolution of 10m to 100m and are used for cartography and terrestrial resources surveying applications, whereas local area level remote sensing satellite systems offer higher resolution. (Maini, 2011)

2.4.3. Passive Imaging Scanning Sensors

The multispectral scanner (MSS) is the most commonly used passive scanning sensor. It operates in a number of different ways and can be categorized into three basic types depending upon the mechanism used to view each pixel. These include optical mechanical scanners, push broom scanners and central perspective scanners.

2.4.4. Optical Mechanical Scanner

This is a multispectral sensor where the scanning is done in a series of lines oriented perpendicular to the direction of the motion of the satellite using a rotating or an oscillating mirror. They are also referred to as across-track scanners. As the platform moves forward over the Earth as shown in Figure 2.3, successive scans build up a two-dimensional image of the Earth's surface. Hence optical mechanical scanners record two-dimensional imagery using a combination of the motion of the satellite and a rotating or oscillating mirror scanning perpendicular to the direction in which the satellite is moving. (Maini, 2011)

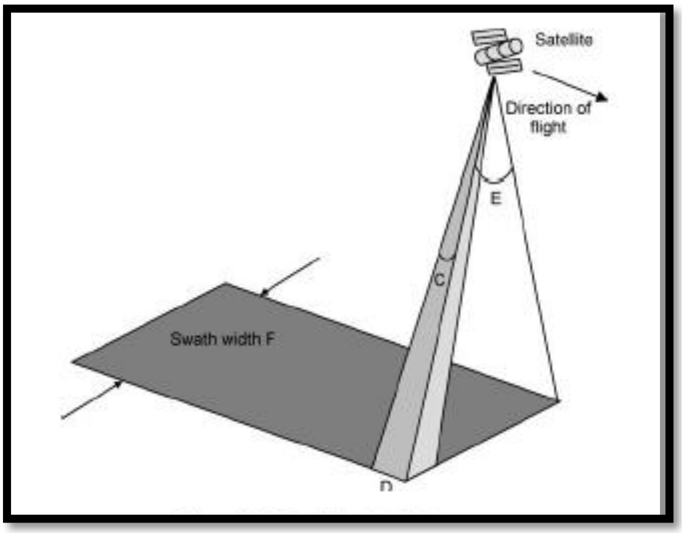

Figure 2.3: Optical mechanical scanner, (Maini, 2011)

2.4.5. Push Broom Scanners

A push broom scanner (also referred to as a linear array sensor or along-track scanner) is a scanner without any mechanical scanning mirror but with a linear array of semiconductor elements located at the focal plane of the lens system, which enables it to record one line of an image simultaneously. (Maini, 2011). Figure 2.4 shows the concept of the push boom scanner.

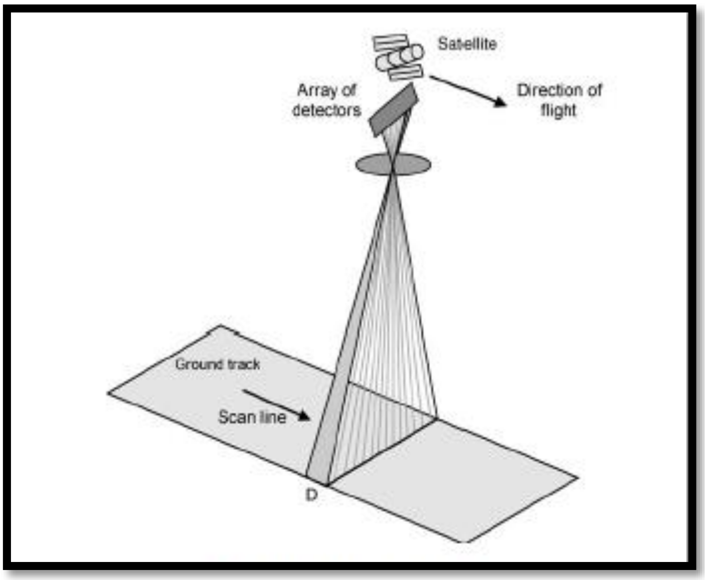

Figure 2.4: Push boom scanner, (Maini, 2011)

2.4.6. Central Perspective Scanners

These scanners employ either the electromechanical or linear array technology to form image lines, but images in each line form a perspective at the center of the image rather than at the center of each line. In this case, during image formation, the sensing device does not actually move relative to the object being sensed. Thus all the pixels are viewed from the same central position in a manner similar to a photographic camera as shown in Figure 2.5. This results in geometric distortions in the image similar to those that occur in photographic data. (Maini, 2011)

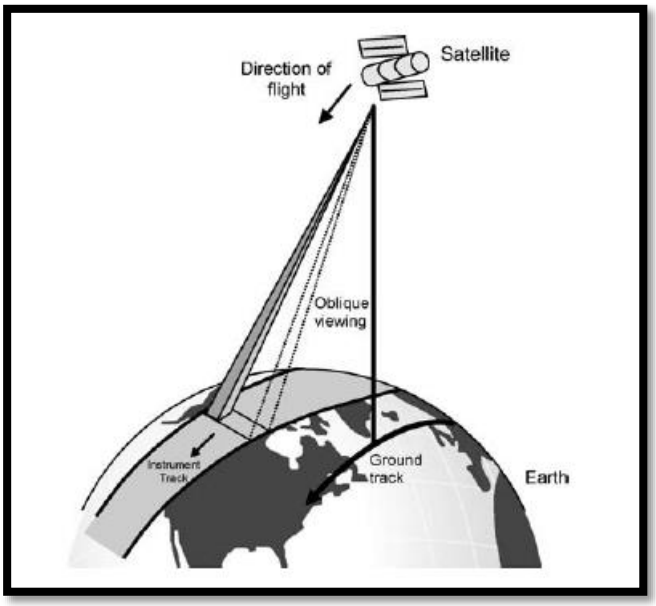

Figure 2.5: Oblique viewing, (Maini, 2011)

2.4.7. Passive imaging Non-scanning Sensors

Passive non-scanning imaging sensors include still multispectral and panchromatic cameras and television cameras. Camera systems employ passive optical sensors, a lens system comprising of a number of lenses to form an image at the focal plane and a processing unit.

The ground coverage of the image taken by them depends on several factors, including the focal length of the lens system, the altitude of the satellite and the format and size of the film. (Maini, 2011)

3. MISSION DESIGN

The mission designing starts with selecting the aim of the satellite then determining all the factors those lead to successfully achieving the mission goals and choosing from the different alternatives available for such a mission.

The mission requirement should be set, and the orbital parameters should be determined. The kind of images that the satellite will capture should be chosen.

Then we need to name all the capabilities of the mission, to answer the questions of when and where the service can be provided and how?

3.1. Requirements

- HRC with GSD 1 m for Panchromatic and 4 m for multi-spectral.
- Ten years lifetime.

3.2. Orbital Parameters

We need the orbit to allow the satellite to take images of Sudan using an optical imager, so it should be in the daytime. The best-case condition occurs when the atmosphere is clear; hence to take clear pictures while achieving sufficient solar illumination conditions. This opportunity often can be found in the mornings (10:00-11:00 Local Time).

We have to specify the type of the orbit, the altitude, LTAN and repeat ground-track.

3.2.1. LTAN

We want to design the satellite to make observations in Sudan during morning at 10 a.m. local time.

3.2.2. Altitude and inclination

Remote sensing satellites often have sun-synchronous, recurrent LEO orbits, allowing them to observe the same area with the same imaging angle periodically with a periodicity of two to three weeks.

They cover a particular area on the surface of the Earth at the same local time, thus observing it under the same illumination conditions. This is an important factor for monitoring changes in the images taken at different dates or for combining the images together, as they need not be corrected for different illumination conditions. (Maini, 2011).

For our design we will have 650 km altitude because this is the typical values for the Chinese launch providers those will be targeted for the project launch phase.

From a lower altitude the required angular resolution is not as much as from higher levels so simpler imager design is needed. On the other hand, an increased flying height improves the revisit time and the time for changing from one area to another.

Figure 3.1 is obtained using a MATLAB code, it shows the relationship between the inclination in degrees and the altitude in kilometers for the sun-synchronous orbits.

The inclination for our design will be about 98 degree. The exact value will be calculated by the STK simulation program.

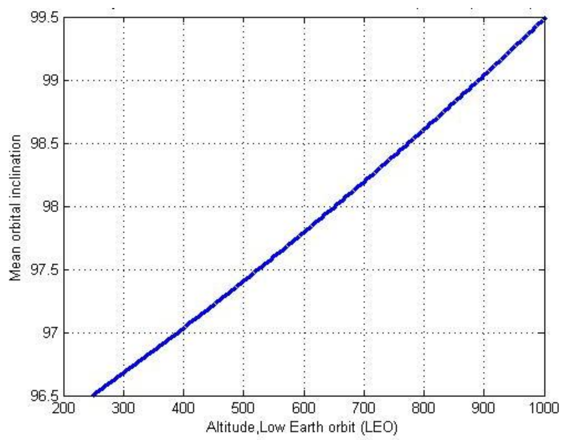

Figure 3.1: Sun synchronous orbit altitude vs inclination.

Satellite orbits are matched to the capabilities and objectives of the sensors they carry.

The satellite passes over the equator at 14:00 local time, to make use of the illumination of the sun in taking the images. This allows the satellite to pass over Khartoum in a suitable daytime for two passes at least, those passes will be for imaging. The satellite also will have a communication window at night-time passes, those will be dedicated to downlink processes.

We assume the worst case where we cannot do both imaging and downlinking in the same pass because of power considerations.

The Figure 3.2 shows one day ground track of SudaSat-1 created by STK, the green part of ground track shows the part of the pass where the satellite is seen by ground station, while the orbital parameters are listed in Table 3.1

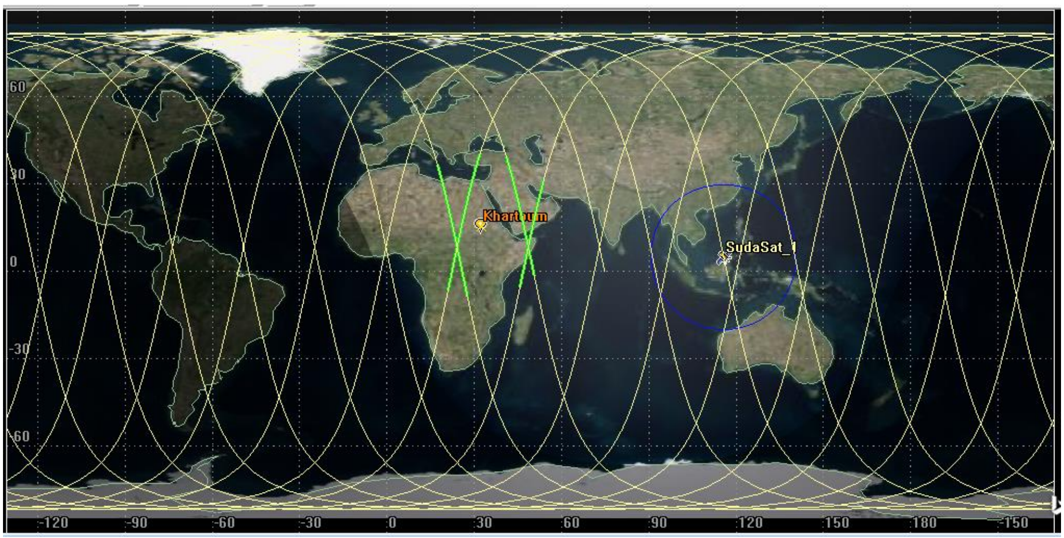

Figure 3.2: SudaSat-1 24-hours ground track (STK)

Table 3.1 : SudaSat-1 orbital parameters

Orbit Epoch	26 Jun 2020 09:00:00.000 UTCG
Semi-major Axis	7028.14 km
Inclination	98.0687 degrees
Eccentricity	0
RAAN	124.465 degrees

Table 3.2 contains a report generated by STK for communication window.

Table 3.2 : Access time and durations for 3 days

No.	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	Duration (min)
1	26 Jun 2020 10:37:24.512	26 Jun 2020 10:48:41.454	676.942	11.28236667
2	26 Jun 2020 12:13:18.396	26 Jun 2020 12:25:44.921	746.525	12.44208333
3	26 Jun 2020 22:43:08.804	26 Jun 2020 22:53:14.124	605.320	10.08866667
4	27 Jun 2020 00:18:25.184	27 Jun 2020 00:31:19.773	774.590	12.90983333
5	27 Jun 2020 11:03:54.367	27 Jun 2020 11:16:43.738	769.371	12.82285
6	27 Jun 2020 12:41:48.115	27 Jun 2020 12:52:10.149	622.034	10.36723333
7	27 Jun 2020 23:09:29.789	27 Jun 2020 23:21:48.492	738.703	12.31171667
8	28 Jun 2020 00:46:24.734	28 Jun 2020 00:57:53.180	688.445	11.47408333
9	28 Jun 2020 09:59:05.109	28 Jun 2020 10:04:01.364	296.255	4.937583333
10	28 Jun 2020 11:30:58.404	28 Jun 2020 11:44:20.027	801.623	13.36038333
11	28 Jun 2020 13:11:40.547	28 Jun 2020 13:17:16.759	336.212	5.603533333
12	28 Jun 2020 23:36:26.813	28 Jun 2020 23:49:41.957	795.144	13.2524
13	29 Jun 2020 01:15:04.109	29 Jun 2020 01:23:36.804	512.695	8.544916667
14	29 Jun 2020 10:23:43.701	29 Jun 2020 10:33:38.399	594.698	9.911633333
15	29 Jun 2020 11:58:32.315	29 Jun 2020 12:11:33.099	780.784	13.01306667
16	29 Jun 2020 22:29:40.430	29 Jun 2020 22:37:40.780	480.350	8.005833333
17	30 Jun 2020 00:03:48.870	30 Jun 2020 00:17:04.500	795.630	13.2605
	Minimum duration		296.255	4.94
	Maximum duration		801.623	13.36
	Average duration		647.960	10.8

3.2.3. Drag

To successfully get on with the designed lifetime of the satellite we shall consider the orbit drag, this will affect the propulsion subsystem's mass in the satellite.

3.3. Acquisition Modes

For both PAN and MS we have two modes of operations

- High Resolution Strip Mode

8 km swath width, 1x1 spatial resolution in PAN channel.

- Wide Swath Mode

300 km swath width, 10x10 spatial resolution in PAN channel.

3.4. Swath Width

As the satellite revolves around the Earth, the sensors onboard it see a certain portion of the Earth's surface. The area imaged on the surface is referred to as the swath.

The swath width for space-borne sensors generally varies between tens of kilometers to hundreds of kilometers. The satellite's orbit and the rotation of Earth, work together to allow the satellite to have complete coverage of the Earth's surface.

The image swath width for this design will be 8 km for the strip map mode, and 300km for the wide swath mode.

3.5. Resolution

As in requirement the designed resolution is 1 m GSD for Panchromatic and 4 m for multi-spectral.

Also the satellite can provide lower resolution as in wide swath images modes.

3.6. Sensors Selection

For high-spatial-resolution systems, satellite movement becomes an issue because of motion blur, just as occurs in regular photography of rapidly moving targets. A simple calculation can estimate exposure time.

The exposure time equals the designed GSD divided by the ground Speed at designed altitude

In our case 1.0 GSD over 6834.432 m/s. This gives us 0.146 ms.

Even with a large camera aperture, an acceptable signal-to-noise ratio cannot be achieved by imaging with a single CCD line. A transfer delay and integration system (TDI), an asynchronous imaging mode or staggered CCD lines, or a combination of these, is required.

These considerations will be taken into account when implementing the imager.

3.7. Data Size

Here we should determine the number of the images that the satellite can take per orbit, per every revisit and every day. We have to determine the length of the image in all modes.

The satellite has to take images with length 400 Km for both PAN and MS as the default length of the image in Strip Map Mode and 2000 km in the Wide Swath Mode.

A custom image length can be provided with custom commands.

3.8. Earth Station (Ground Station)

The SudaSat-1 mission control ground station will be located in Khartoum, capital city of Sudan. The received images will for the benefit of the government of Sudan and can be utilized for monitoring different resources including forests, agricultural fields, wild animals, etc. Image can be available commercially for the benefit of private sector institutions. Table 3.3 shows earth station antenna specifications.

Table 3.3: Earth station antenna specifications

Antenna type	Parabolic dish
Antenna Diameter	7.2 m
Antenna Efficiency	60 %
Antenna Azimuth Range	360 degrees
Antenna Elevation Range	180 degrees

3.8.1. Communication Window

The satellite has 4-5 communication windows with the ground station in Khartoum per day. At least two at daytime and two at night.

The effective average duration is 9 minutes.

The night time contact with the ground station will be dedicated for the data downlink. This gives us 18 minutes of downlink duration.

4. SATELLITE CONFIGURATION BASELINE SATELLITE DESIGN

4.1. Baseline Functionality

In order for the satellite mission to be accomplished the payload needs a platform to serve it.

The payload needs to be protected from the harsh environment in the space, it needs power and control, and it needs to transfer the data obtained to the ground. The baseline ensure to fulfill all these stuff by providing the required subsystems.

4.2. Platform Subsystems

The control and telemetry gathering is done by the satellite management subsystem.

4.2.1. ADCS

Attitude requirements are affected by the orbit selection. Its importance come from its responsibility to pointing the camera to the target, pointing the antennas to the ground station and pointing of solar panels to the sun when the satellite is in charging mode.

In our design we will have three axis stabilized satellite.

There will be a separate computer with real-time software to perform all the ADCS functions, it will collect and process sensor data, estimate orbit and attitude, calculate controller outputs and determine actuator commands.

This computer is connected to the main computer in the satellite management subsystem which can restart and reset the ADCS computer.

4.2.2. Communication

The communication subsystem design is done in a separate study. As a result of that study Table 4.1 shows the general design aspects for communication subsystem.

Table 4.1: Communication main design factors

Average Communication Window for a GS per pass	9 minutes
Average number of passes per day	4 times
Average number of night passes	2 times
Payload Net Data Rate	230 Mbps
Telemetry Net Data Rate	512 Kbps
Frequency band	x-band (8.025 - 8.400) GHz s-band (2.200 - 2.290) GHz
X-band Transmitter Mass	4.4 kg
X-band Antenna Mass	3.3 kg
S-band Antenna Mass	500 g
Modulation	QPSK
Encoding	Convolutional encoding concatenated with an outer Reed-Solomon coding schemes

4.2.3. Power

All power system operations such as production, storing, distribution, conditioning and protection is assumed satisfying the requirements of all systems.

4.2.4. Structure

The structure involves the spacecraft separation system, deployable solar panels, steerable solar panels, steerable antennas, deployable antennas and satellite protection shields.

Although impressive advances in processing capability and storage capacity have been made for terrestrial uses, for space-based application these devices must be hardened against radiation. (Laurence, 1994)

This is also assumed to satisfy all the requirements to achieve the mission success.

4.3. Platform Selection

There are many buses can be used for remote sensing optical imagery satellites.

For the purpose of this design a Chinese bus from China Academey of Space has been chosen.

CAST2000 Bus is shown in Figure 4.1 and it has these technical specifications:

- Areas of Application includes Earth Observations
- 3-axis stabilization, sway maneuver capability
- Attitude stability: ≤0.001°/s
- Attitude control accuracy: ≤0.1°
- Attitude measurement accuracy: ≤0.03°
- Mass of 400 kg and Payload capacity of 600 kg.
- Solar Array Output Power ≥ 1 KW (BOL) ≥ 900W (EOL).

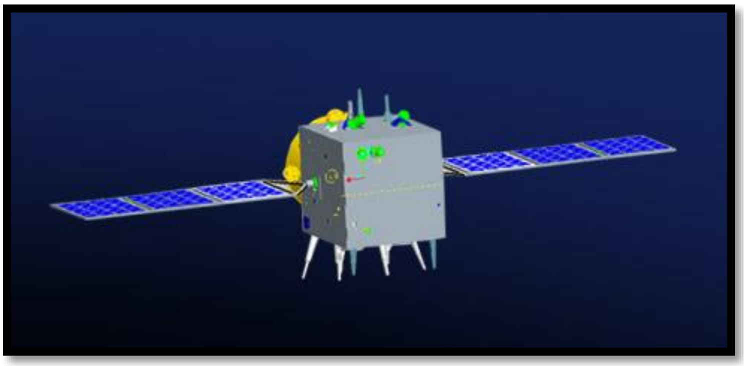

Figure 4.1: CAST2000 bus. (Url-5)

The CAST2000 bus reportedly delivers improvements in antimagnetic, vibration, and radiation protection. (Parks**,** 2012)

It has flight verification, CAST2000 is a compact satellite platform characterized by its high performance, expandability and flexibility. It is fitted with an S-band TT&C subsystem, X-band data transmission subsystem and 3-axis attitude stabilization, and is able to offer highly precise control, large-range sway maneuver, flexible orbit maneuver, highly integrated housekeeping and highly effective power supply. (Url-5)

This platform has already been successfully applied in several Chinese and international satellites and its performance and reliability have proven to be excellent. Satellites use CAST2000 platform:

- OceanSat-1A
- OceanSat-1B
- Huanjing-A
- Huanjing-B
- VRSS-1 satellite

5. SATELLITE CONTROL AND MANAGEMENT SUBSYSTEM DESIGN

The basic functions of the simplest spacecraft requires extensive contact with ground stations for control, command, communication, and data return, these tasks need to be managed and controlled with a sufficient computer processing power to run all spacecraft subsystems with -in many cases- a high degree of autonomy.

The subsystem handles all data sent and received by the spacecraft, including images, control data and spacecraft or payload operations. The system is connected to the transmitter and receiver units that are the sole point of passage for data entering or leaving the spacecraft. A spacelink is a communication link between the spacecraft and its associated ground system or between two spacecraft.

5.1. Objective

The platform control functionality is centrally driven by the functionality included in the on board software system. The performance of the onboard software is limited by that of the hardware of the OBC. (Prabu, 2015)

The objectives of the subsystem can be listed as following:

- Connecting the instruments and sensors.
- Failure detection, isolation and recovery features.
- Processing and performing the commands from the ground station.
- Altitude determination and control.
- Gathering the subsystems' data and prepare the satellite's telemetry data.
- Perform all the processes of image acquisition successfully by ensuring imaging the desired area.
- Task Scheduling for Satellite Imagery and data download.
- Support control of all nominal platform and payload functions from ground.
- Automated Mission Planning.

5.2. Subsystem Requirements:

Processors and recorders are used for controlling the spacecraft and for storing and processing data. Computers and recorders of large capacity are advantageous, for control, storage, and processing of data; spacecraft health monitoring; and autonomous operation. (Laurence, 1994)

The main requirement for the subsystem and its components are:

- All shall provide the numeric performance for the mission purpose, for platform data processing, vehicle control, payload data handling and other functions.
- The entire assembly of the OBC shall be mechanically robust to withstand sine vibration and shock loads during launch and bear up the temperature cycles.
- In orbit they have to withstand the according electromagnetic conditions, and have to resist the high energetic particle radiation doses.
- The OBCs have to outlive challenging thermal conditions.
- Execution of predefined commanding sequences.
- Instrument health/status monitoring.
- Science data acquisition and packetization.
- Self-test and SW verification facilities;
- Memory load and dump, EEPROM write and check.

5.3. Subsystem Architecture

We will use centralized architecture to connect the subsystem with other satellite parts because of its high reliability where failures along one interface will not affect the other interfaces.

The centralized architecture has point-to-point interfaces between processing units of the management subsystem and other terminals of the satellites as shown in Figure 5.1.

This subsystem encompasses:

- Telecommand and Telemetry Modules
- On-board Computers (OBC)
- On-board Software of the Satellite (OBSW)
- Memories and Data storage.
- Remote Terminal Units.
- ADCS computer.
- Protocols and Data Busses.

These components are shown in Figure 5.2.

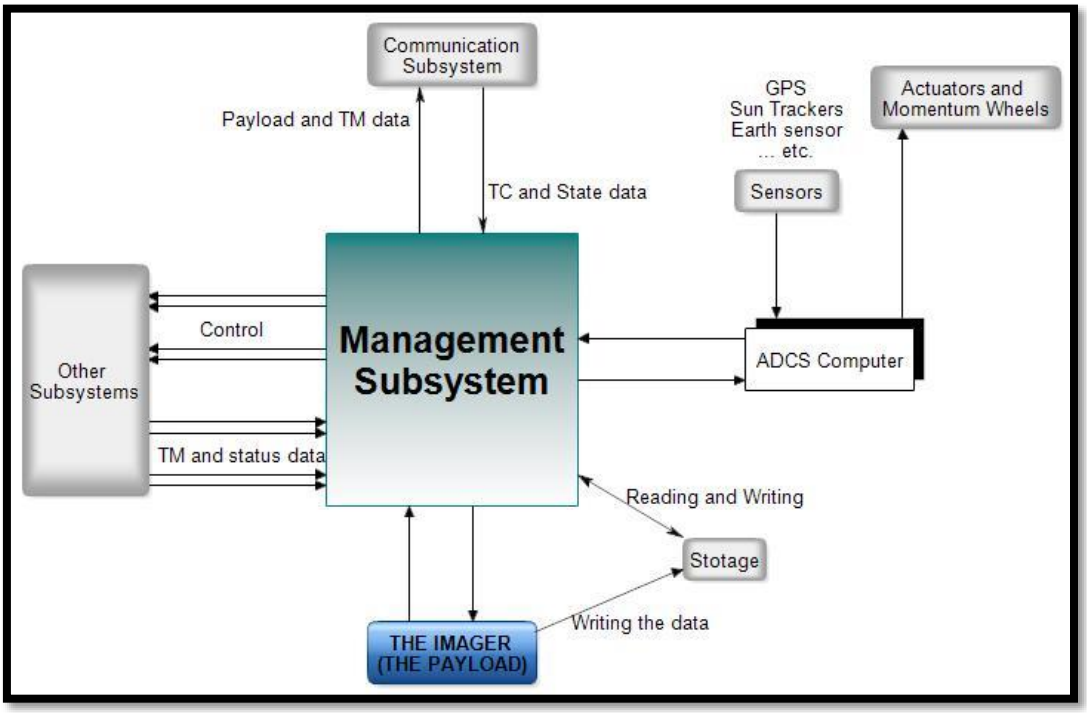

Figure 5.1: Management Subsystem and other subsystems

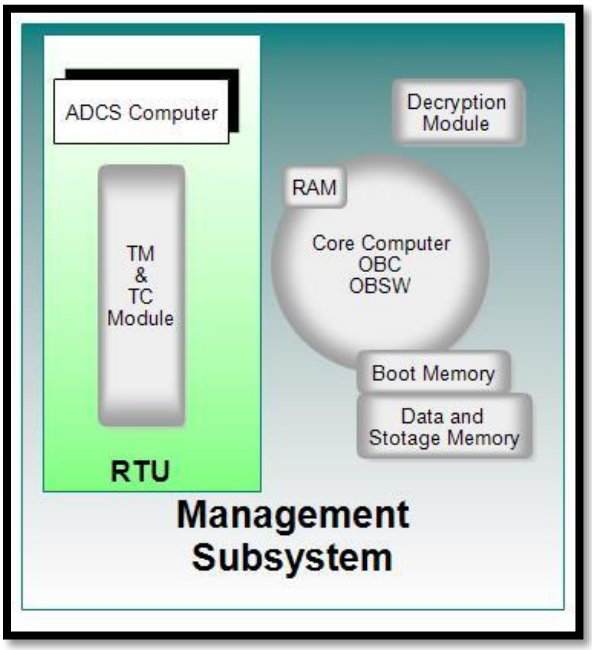

Figure 5.2: Components of the Management Subsystem

5.4. On-Board Computer OBC

5.4.1. Overview

The term "On Board Computer" indicates, rather obviously, any unit flying on board a satellite, which provides processing capability. However, the On Board Computer, or OBC, more commonly refers to as the computer of the satellite's avionic sub-system, i.e. the unit where the On Board Software run. In turn, the "On Board Software", despite the rather generic label, is known as the software implementing the satellite's vital functions such as: attitude and orbit control in both nominal and non-nominal cases, telecommands execution or dispatching, housekeeping telemetry gathering and formatting, on board time synchronization and distribution, failure detection, isolation and recovery, etc.

Based on the above, the very essence of an OBC is the microprocessor board, consisting of microprocessor, non-volatile memories, volatile memories and the companion chip that connects the microprocessor to different peripherals.

However, in space as well as in the consumer market, as the shrinking of the electronic components enables it, the trend is towards more dense and integrated systems, aiming at continuous reduction of volume, mass, and power consumption.

A modern On Board Computers, in fact, not only provides the aforementioned processing resources, but it does include other functions in the same box such as:

- DC/DC Power conversion and regulation
- Ground Telecommand Decoding
- Packet Telemetry Formatting
- On Board time management
- Autonomous Reconfiguration
- Local Mass Memory function
- Housekeeping telemetry
- Interfacing with other subsystems

These functions are usually implemented in hardware following a modular approach with one module providing one or more functions.

This is the Core of the subsystem it contains the microprocessor, system clock, watch dog and master time base.

5.4.2. Throughput Estimation

We need to estimate the size and throughput of onboard software then we begin defining the computer system, we use the software estimates in conjunction with requirements for spare processing to determine how much computing power we need to perform the mission. (Larson 1999).

Table 5.1 below shows an estimation for the needed throughput for different function of the system, the data management subsystem is 1 instruction per byte of data, we have the data rate of the payload data as 365 Mbps as the maximum value (will be calculated in Data Budget section), this gives us 45.625 MBytes per second. 46 MIPS will add an enough margin to also cover the other data in the storage.

As in our design the decryption takes place when transmitting the data, so we will need to calculate the throughput from the downlink data rate.

Table 5.1: System Throughput estimation

Function	Peak Throughput (MIPS)
Data Management	46
DMA Control	1
ADCS Computer Management and Control	10
Communication Subsystem and decryption	40
Satellite Management and Control Functions	100
Operating System	10% of the above
Margin	50% of the above
Total	325.05

5.4.3. On-board Computer specifications

- Central processor
    - Processor clock 2 GHz. (since the selected memory input data rate is 2Gbps – see Storage Memory Selection section)
    - Minimum throughput of 216.7 MIPS.
    - Minimum Internal data rate of 365 Mbps (see Data Budget section)
    - Eight bits quantization of the data.
    - DMA: Without DMA, when the CPU is using programmed input/output, it is typically fully occupied for the entire duration of the read or write operation, and is thus unavailable to perform other work. With DMA, the CPU first initiates the transfer, then it does other operations while the transfer is in progress, and it finally receives an interrupt from the DMA controller when the operation is done. This feature is useful at any time that the CPU cannot keep up with the rate of data transfer, or when the CPU

needs to perform useful work while waiting for a relatively slow I/O data transfer. (Url-6)

    - Support MID and SpaceWire Buses.

- Watchdog and interrupt control
- Memory:
    - Solid-State memory for data recording.
    - Should be EDAC-protected memory to have a protection against soft errors by relying on error correcting codes.
    - Needed Storage capacity of 60 Gbyte.
    - Boot memory: Each onboard computer includes a data storage area of non-volatile memory which is persistent even after hard reboot of the OBC by means of a power reset. This non-volatile ROM holds the boot loader for the OBSW and the reference image of the OBSW. (Eickhoff, 2012)
    - RAM

5.5. Remote Terminal Unit

The Remote Terminal Unit (RTU) is a unit that is usually present on medium-large size spacecraft. The RTU offloads the On Board Computer from analogue and discrete digital data acquisition and actuators control tasks and it represents an example of implementation of distributed control system on board a satellite. The RTU is usually not-intelligent and it is interfaced with the On-Board Computer with serial communication busses.

The RTU is powered by the satellite Power Conversion Unit (PCU) or Power Conversion and Distribution Unit (PCDU) and it is controlled by the On-Board Computer Unit (OBC) through the platform bus.

A list of the typical tasks of a RTU:

- To gather the analogue and digital telemetry from sensors and units (Temperature, Digital Status).
- To provide the conditioning for analogue sensors.
- To control AOCS actuators and sensors (as Reaction Wheels, Gyros, Star Trackers, Sun Sensors, GPS, Magnetometers, Magneto-torquers).

- To control the Propulsion.
- To control Solar Array Drive Equipments.
- To distribute power to heaters.

5.6. Telecommand and Telemetry Modules

This part deal with the satellite status reports which stored and send to the GS to update the satellite position and satellite situations has these functions**:**

- Receive ground TCs
- Depacketize TCs
- Handle TC Queues / Procedures
- Parameter Monitoring
- Event Handling
- HK TM Generation
- Submit TM

5.6.1. Telecommand

The Telecommand element receives and executes remote control commands from the control center on Earth to perform tasks related to the platform subsystems functions, configuration, position and velocity or the payload operations.

The Telecommand are multiplexed to the intended addresses. There are two categories of commands: the high priority and the normal commands. The high priority commands (HPC) are sent to the Command Pulse Distribution Unit (CPDU) for immediate execution. The CPDU is either internal to the TC decoder or external and it’s implemented in hardware, i.e. no software is involved in the execution of HPCs. The normal commands are sent off to the OBC CPU to be either processed or relayed on the system bus.

The control commands received by the command element on the satellite are first stored on the satellite and then retransmitted back to the Earth control station via a telemetry link for verification. After the commands are verified on the ground, a command execution signal is then sent to the satellite to initiate intended action.

A space link protocol is a communications protocol designed to be used over a space link, or in a network, that contains one or multiple space links. The basic data flow over a space link is made of Telemetry (TM) and Telecommand (TC) data. Thus, the TM downlink and TC uplink provide a communication channel between the spacecraft and the ground operators.

On the uplink, the C&DH system receives and decodes all commands and data for both platform and payload operations from the communications system. These commands (TCs) are then directed to the appropriate subsystem or executed directly at platform level. The handling of payload commands would generally not be done by the C&DH system, but would instead be passed, fully encapsulated, directly to the payload. TC is split into:

- Direct commands to the spacecraft for reconfiguration
- Application-specific commands

5.6.2. Telemetry

The Telemetry encoder collects the telemetry packets from different sources, assembles them into frames and sends them to the TM/TC transceiver to be downloaded to the ground.

During the orbital injection and positioning phase, the telemetry link is primarily used by the tracking system to establish a Satellite-to-Earth control center communications channel.

After the satellite is put into its intended orbit, its primary function is to monitor the health of various subsystems on board the satellite. It gathers data from a variety of sensors and then transmits that data to the Earth control center. The data include a variety of electrical and non-electrical parameters. The sensor output could be analogue or digital.

Wherever necessary, the analogue output is digitized. With the modulation signal as digital, various signals are multiplexed using the time division multiplexing (TDM) technique. Since the bit rates involved in telemetry signals are low, it allows a smaller receiver bandwidth to be used at the Earth control center with good signal-to-noise ratio. (Maini, 2011)

On the downlink, the C&DH system collects various types of data acquired from the platform subsystems, and multiplexes it into transfer frames for transmission to ground. TM data can be split into:

- Spacecraft HK data.
- Orbit (position) data.
- Telecommand reception status (CLCW) .
- Memory data.

5.6.3. Telemetry Data

Spacecraft HK data consist of:

- Current in all busses.
- Voltages in all notes.
- Temperature of solar cells, all subsystems and all satellite faces.

5.7. On-Board Software of the Satellite (OBSW)

The OBSW needs to be a

- Real-time control software.
- Allowing both interactive spacecraft remote control and automated/autonomous control.

- The onboard software concept typically today is a service based architecture covering several control and input/output, (I/O), levels:

  ◊ Data I/O handlers and data bus protocols.

  ◊ Control routines for payloads, AOCS, thermal and power subsystems.

  ◊ Up to Failure Detection, Isolation and Recovery routines.

5.8. Processor Selection

The processor for the mission will be an Integrated Spacecraft Computer (ISC) from The General Dynamics Advanced Information Systems (GDAIS).

In the design we choose Redundant Platform Controller which is shown in Figure 5.3 below. The specification is listed in Table 5.2

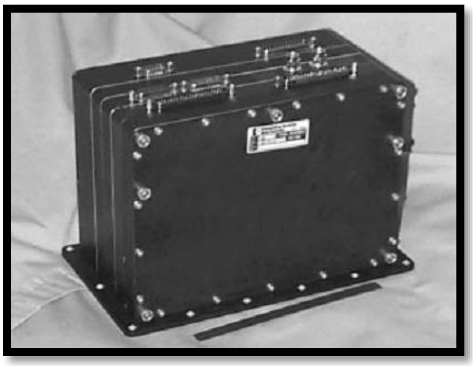

Figure 5.3 Payload Controller for Processing and Data Handling Units (Url-10)

Table 5.2: Processor specifications (Url-10)

Parameter	Value
Instruction Set	PowerPC
Weight	9 Kg
Other Interfaces	Telecommand and Telemetry, Analog and Digital Interfaces
Typical Size (Exclusive of Mounting Flange)	9.5 x 6.5 x 9.3 cm
System Bus	2-1553, SpaceWire
Typical Power (Watts)	10 - 35
Peak Throughput	480 MIPS
DMA Channels per Active Side	10
Processor RAM	512 MB
Non-Volatile Program Storage	32 MB
Lifetime	> 10 years

5.9. Data Management

5.9.1. Raw Data

A raw data product has no radiometric or geometric correction, but the scan lines are re-aligned in the same across-track direction.

RAW data needs to be processed with specialized equipment. This format is not suitable for inexperienced users.

The raw images taken from the satellite are referred to as primary images. These raw images are seldom utilized directly for remote sensing applications but are corrected, processed and restored in order to remove geometric distortion, blurring and degradation by other factors and to extract useful information from them.

5.9.2. Image of a strip

In our design we need the image to be 400 km strip for PAN and for MS too as the default strip mode and 2000 km strip is the default of the wide swath width mode.

5.9.3. Compression

Satellite image compression is needed to deliver tremendous volumes of data to the ground. In order to utilize remote sensing images effectively and completely reconstruct the encoded image without loss of information, lossless compression is widely used and it gives moderate compression ratio. (Swamy, 2012)

Image compression reduces redundancy in data representation in order to achieve saving in the cost of storage and transmission. Image compression compensates for the limited on-board resources, in terms of mass memory and downlink bandwidth and thus it provides a solution to the “bandwidth vs. data volume”

We will use a lossless compression with 0.7 ratio.

5.9.4. Encryption

For security purposes we will use high speed and real-time TRIPLE-DES encryption for the payload data. Encryption will be an optional operation.

5.9.5. Data Formatting

Imaging Remote Sensing data is organized in a matrix. The columns are usually termed as samples, and the rows as lines. As an image scene contains information from several bands, there can be different ways to organize the data. The data is stored as a binary stream of bytes in either Band Sequential (BSQ), Band Interleaved by Pixel (BIP), or Band Interleaved by Line (BIL) format.

- BSQ is the simplest format, with each line of data followed immediately by the next line of the same spectral band. BSQ format is optimal for spatial (X,Y) access to any part of a single spectral band.
- BIP format provides optimal spectral processing performance. Images stored in BIP format have the first pixel for all bands in sequential order, followed by the second pixel for all bands, followed by the third pixel for all bands, etc., interleaved up to the number of pixels. This format provides optimum performance for spectral (Z) access of the image data.
- BIL format provides a compromise in performance between spatial and spectral processing and is the recommended file format for most Remote Sensing processing tasks. Images stored in format have the first line of the first band followed by the first line of the second band, followed by the first line of the third band, interleaved up to the number of bands. Subsequent lines for each band are interleaved in similar fashion.

As an image file contains only pixel values, additional information is needed in order to display it, and to keep track of it. Depending on the software used, this metadata is located either at a separate file (usually an ASCII file with the same name, using a different extension), or in the same file containing the data, before the data. This information is known as header, or documentation.

5.9.6. Data Protection

Satellite will be exposed to high level of radiation. When electronics are exposed to radiation three things will happen:

- Slowly the chip will degrade until finally not working.
- Bit errors occurring when a bit flips.
- Latch up resulting in a short circuit.

The components are space proven and radiation hardened parts, this is the hardware solution for the bit flip problem, we also have a software solution to reduce the effect by using code correction by using EDAC technology which provide protection against soft errors by relying on error correcting codes.

5.10. Data Budget

5.10.1. Payload Data Volume

The volume of the data is the amount of storage size needed to save the data in as a digital data. The analogue pixel in the image is presented in the memory by a word, this word equals 8-bits in this design.

The volume of the digital data can potentially be large in high resolution imaging satellite. In our case it is the MS data volume plus the PAN data volume.

For multispectral data, it covers four different wavelength bands with a four times lower resolution than the PAN image.

Calculations:

Number of pixel for an image strip:

$$Number\ of\ pixels = length\ (m) \times width\ (m) \div Resolution^2 \tag{5.1}$$

Memory for the whole image strip in bits:

$$data\ volume\ (before\ compression) = number\ of\ pixels\ \times quantization\ bits \tag{5.2}$$

$$data\ volume = data\ volume\ (before\ compression)\ \times compression\ ratio \tag{5.3}$$

Wide Width Image Data Volume

PAN image:

As stated in the operation modes wide-width image covers an area of 2000x300 km^2 on the ground with a pixel separation of 10 m. So there are about 200000 x 30000 pixels per image. Each pixel intensity in each band is coded using an 8-bit (one byte), then we will make 0.7 ratio compression.

$$Number\ of\ pixels = 2{,}000{,}000\ m \times 300{,}000\ m \div 10^2$$

$$= 200{,}000\ px \times 30{,}000\ px = 6 \times 10^9\ px$$

$$data\ volume\ (before\ compression) = 6 \times 10^9 \times 8 = 48 \times 10^9\ bits$$

$$data\ volume = 48 \times 10^9 \times 0.7 = 33.6 \times 10^9\ bits = 4.2 \times 10^9\ Bytes$$

$$data\ volume = 4.2 \times \frac{10^9}{1024^2} = 4005.43\ Mbytes$$

So the volume of one default size image in PAN is 4005.43 Mbytes.

MS image:

For the MS the resolution is less by factor of 4. It will be 40 meters.

We do the calculation for only one band:

$$Number\ of\ pixels = 2{,}000{,}000\ m \times 300{,}000\ m \div 40^2$$

$$= 50{,}000\ px \times 7{,}500\ px = 375 \times 10^6\ px$$

$$data\ volume\ (before\ compression) = 375 \times 10^6 \times 8 = 3 \times 10^9\ bits$$

$$data\ volume = 3 \times 10^9 \times 0.7 = 2.1 \times 10^9\ bits = 262.5 \times 10^6\ Bytes$$

$$data\ volume = 262.5 \times \frac{10^6}{1024^2} = 250.34\ Mbytes$$

For all bands of MS image =

$$250.34 \times 4 = 1001.36\ Mbyte$$

So the volume of one default size image in MS is 1001.36 Mbytes.

The total data volume for the **Wide Width Image is**

$$1001.36 + 4005.43 = 5006.79 \;\; Mbyte$$

High Resolution Strip Image Data Volume

With the same procedure we can find that the image size in high resolution strip mode (1m for PAN and 4m MS) with image length 400km and 8 km swath width.

PAN image:

As stated in the operation modes High Resolution Strip image covers an area of 400x8 km2 on the ground with a pixel separation of 1 m.

$$Number\ of\ pixles = 400{,}000\ m \times 8{,}000\ m \div 1^2$$

$$= 3.2 \times 10^9\ px$$

$$data\ volume\ (before\ compression) = 3.2 \times 10^9 \times 8 = 25.6\ \times\ 10^9\ bits$$

$$data\ volume\ = 25.6\ \times\ 10^9\ \times 0.7 = 17.92 \times\ 10^9\ bits = 2.24 \times 10^9\ Bytes$$

$$data\ volume\ = 2.24 \times \frac{10^9}{1024^2} =\ 2136.23\ Mbytes$$

So the volume of one default size image in PAN is 2136.23 Mbytes.

MS image:

For the MS the resolution is less by factor of 4. It will be 40 meters.

We do the calculation for only one band:

$$Number\ of\ pixels = 400{,}000\ m \times 8{,}000\ m \div 4^2$$

$$=\ 100{,}000\ px\ \times 2{,}000\ px = 200 \times 10^6\ px$$

$$data\ volume\ (before\ compression) = 200 \times 10^6 \times 8 = 1.6\ \times\ 10^9\ bits$$

$$data\ volume\ = 1.6\ \times\ 10^9\ \times 0.7 = 1.12 \times\ 10^9\ bits = 140 \times 10^6\ Bytes$$

$$data\ volume\ = 140 \times \frac{10^6}{1024^2} =\ 133.514\ Mbytes$$

For all bands of MS image =

$$133.514\ \times 4 = 534.06\ Mbyte$$

So the volume of one default size image in MS is 534.06 Mbytes.

The total data volume for the **High Resolution Strip Image is**

$$2136.23 + 534.06 = 2670.29 \ \ Mbyte$$

The image size will be 2670.29Mbyte.

5.10.2. The Internal Data Rate Calculation

To design the bus speed of the satellite we need to calculate the internal data rate which is the quantity shows us how fast the satellite should save the image's lines without having an overflow for the imager buffer.

To find the internal data rate we need to find the volume of the image in bits after compression if any, then finding the time needed from satellite to pass over that strip of land where we need its image.

This is calculated by dividing the ground speed of the satellite by the strip length.

$$\text{Internal Data rate} \\ = \text{data volume (Bits)} \times \text{satellite GroundSpeed(m/s)} \\ \div \text{stripLength (m)} \qquad (5.4)$$

The satellite the ground speed is a function of the orbit altitude.

For 650 km orbit, our satellite's ground speed is 6834.432 m/s.

Internal Data rate for Wide Width mode:

$$= 8 \times 5006.79\, M \ \times 6834.432 \div (2 \times 10^6) = 136.874\, Mbps$$

Internal Data rate for High Resolution Strip mode:

$$= 8 \times 2670.29\, M \times 6834.432 \div (0.4 \times 10^6) = 365.00\, Mbps$$

Those data rates are the data flow speed from the instrument into the data bus.

The data rate in High Resolution Strip mode is considered a high data rate, and it will be a main constrain for the OBC and for data bus.

The onboard computer will need to do some management and real-time operations in the memory such as compression and cyphering, this has to be taken into account in selecting core computer capabilities.

5.11. Data Storage

One image size (of wide mode which is larger size than strip mode) as calculated in the data volume is 5006.79 Mbyte, but the satellite should be able to take more than an image before it download them. As in mission design the satellite has 18 minutes of data communication with the GS, the downlink net data rate is at least 220 Mbps.

In this duration the satellite communication system can deliver 29 $Gbytes$ of data per day. The images will be taken at daytime and will be downloaded at night time. Thus the minimum storage size we need is equal to this amount of data.

$$18\ min \times 60\ sec \times 220\ Mbps \div 8 \div 1024 = 29\ Gbytes$$

This storage is for the images to be download in Khartoum GS.

As a design the satellite can serve other GS, thus we make a minimum of 60 Gbytes of storage capacity.

5.12. Storage Memory Selection

Solid State Recorder from Airbus Defence and Space is found in line with the requirements. Figure 5.4 shows the memory and Table 5.3 states its specifications.

The main application field of this memory is storage of optical and radar data.

Figure 5.4 Solid State Memory (Url-11)

Specifications

Table 5.3: Storage Memory Specifications

Mass	20 kg
Width	250 mm
Height	250 mm
Length	300 mm
Power	20 W
Technology	Non-Volatile Flash Storage
Capacity	1 Tbit (128 Gbytes)
input data rate	2 Gbps
Data Interface	SpaceWire, LVDS link, MIL-STD-1553, Wizard Link, Channel Link, GigaLink, RS-422 UART, Parallel
Temperature (operating)	-25 ˚C to +60 ˚C
Temperature (non-operating)	-40 ˚C to +75 ˚C
Radiation Tolerance	up to 40 Krad
Life time	up to 15 years in our orbit

5.13. Protocols and Data Busses

A real improvement in the specification and use of communications protocols is needed in space engineering field and especially in high resolution remote sensing satellite.

Typically, previous developments have harmonized physical interfaces and low-level data link, this has increased development and integration costs and limited the possibility of element reuse without expensive modification. Now in the space researches a development and standardization of protocols above the basic link layer is being performed, this has systematically pursued the use of multilayer protocol stacks resulting in simple integration and more compatibility.

The most common buses used on a spacecraft platform are

- MIL-STD-1553B
- CAN-Bus
- SpaceWire

5.13.1. MIL-STD-1553B

It was originally published by the US Air Force and was designed for use in military aircraft avionics, but has also become commonly used in spacecraft OBDH subsystems. (Eickhoff, 2012)

A MIL bus consists of a “Bus Controller”, (BC), and up to 31 “Remote Terminals”, (RT). The data bus has an A and a B side and thus is redundant by design as in Figure 5.5. Terminals always are connected to both bus sides.

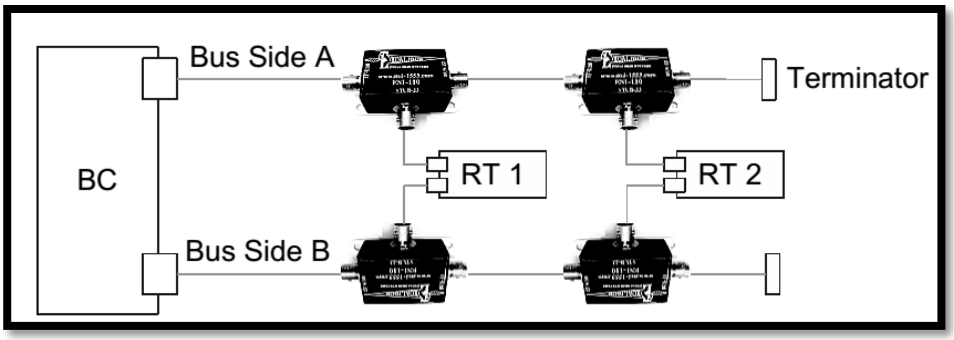

Figure 5.5: Principle of MIL bus (Eickhoff, 2012)

Our computer design is to be compatible with this bus.

5.13.2. CAN-Bus

Controller Area Network was designed to allow microcontrollers and devices to communicate with each other within a vehicle without a dedicated host computer. CAN-bus was designed specifically for automotive applications but now is also used in space industry by Surrey Satellites.

5.13.3. SpaceWire

SpaceWire is a standard for a spacecraft communication network. It is coordinated by the European Space Agency (ESA) in collaboration with international space agencies. SpaceWire electrically uses a current driven signaling via two pairs of wires which makes it robust up to failure of wires.

The current driven implementation in contrast to a voltage driven signal transfer makes SpaceWire also very robust to signal noise or vice versa this technique allows extremely high data rates. SpaceWire can also be operated in full duplex configuration similar to Ethernet but this feature is not usually used in space.

The SpaceWire technology is now being increasingly used for data. It can combine the command and control function with massive data transfer.

We will need SpaceWire in this design mainly because we need relatively high data rate.

SpaceWire is simple to implement and has some specific characteristics that help to support data handling applications in space: high-speed, low-power, simplicity, relatively low implementation cost, and architectural flexibility making it ideal for many space missions.

SpaceWire provides high-speed, bi-directional, full-duplex data-links, which connects SpaceWire enabled equipment. Data-handling networks can be built to suit particular applications using point-to-point data-links and routing switches. (SpaceWire User's Guide, 2012)

SpaceWire is designed to connect high data-rate sensors, large solid-state memories, processing units and the downlink telemetry subsystem providing an integrated onboard, data-handling network. (Parkes, 2005)

5.14. SpaceWire Implementation

The avoidance of possible single point failures is important for most space missions especially for mission critical services. As in Figure 5.6 SpaceWire provides a simple means of adding fault tolerance into a system where it is required.

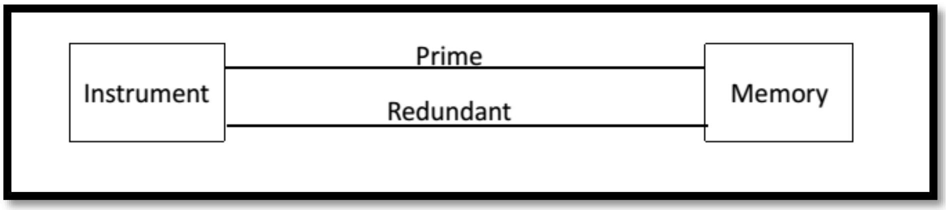

Figure 5.6: Fault Tolerance Links (SpaceWire User's Guide, 2012)

5.15. Operation Modes

- Acquisition mode:

The time required to acquire an image can be split into three distinct segments (Harrison, 1999)

- Scan time - time when the sensor is moving to the correct elevation.
- Idle time - time when the satellite is idle as the task is not yet in range.
- Image time - the time required to acquire an image of the target.

The acquisition mode is the satellite mode during scan and imaging time, the management subsystem gives the ADCS computer an order to maintain the correct orientation for the imager, then it gives an order to the sensor to start imaging when the satellite is exactly passing by the targeted area.

- Battery charging mode:

This mode will be active when there are no enough power and the communication link is about to occur with the Ground station.

The download process is important either because there is no enough storage or the image have a time tolerance. In such a case, the satellite shall shutdown all low priority tasks and work with the minimum power. It gives a command to ADCS computer to point the solar panels to the Sun.

- Recovery mode:

When the satellite faces severe problems which affect its ability to work normally it shutdown itself and reload the onboard software from the boot memory.

- Idle mode:

This is the normal mode of the satellite when there are no communication link with the ground and no imaging tasks. The thermal control is the main task in this mode.

- TC Execution mode:

When the TC module receives a high priority command it forward it to Command Pulse Distribution Unit to be processed. The process of this command can stop imaging and start downloading data to GS.

When it receives a non-urgent command the OBC put it in the schedule list.

5.16. Scenarios and Software Parts Flow Charts

The main loop of the satellite software flow chat is shown below in Figure 5.7.

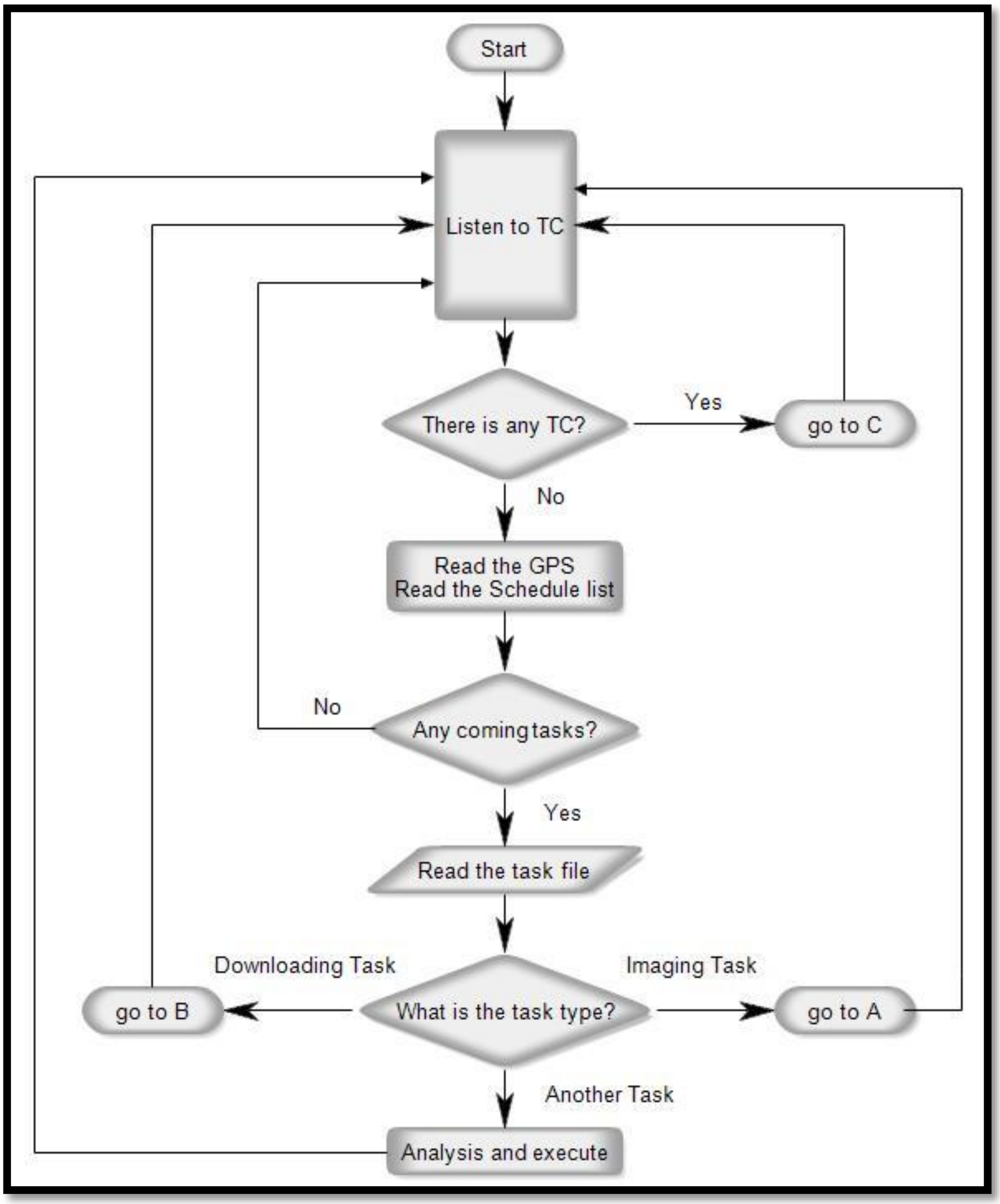

Figure 5.7: The Main Flow Chat Loop

The Figure 5.8 shows the flow chart of the software part that will run if the satellite receives a command.

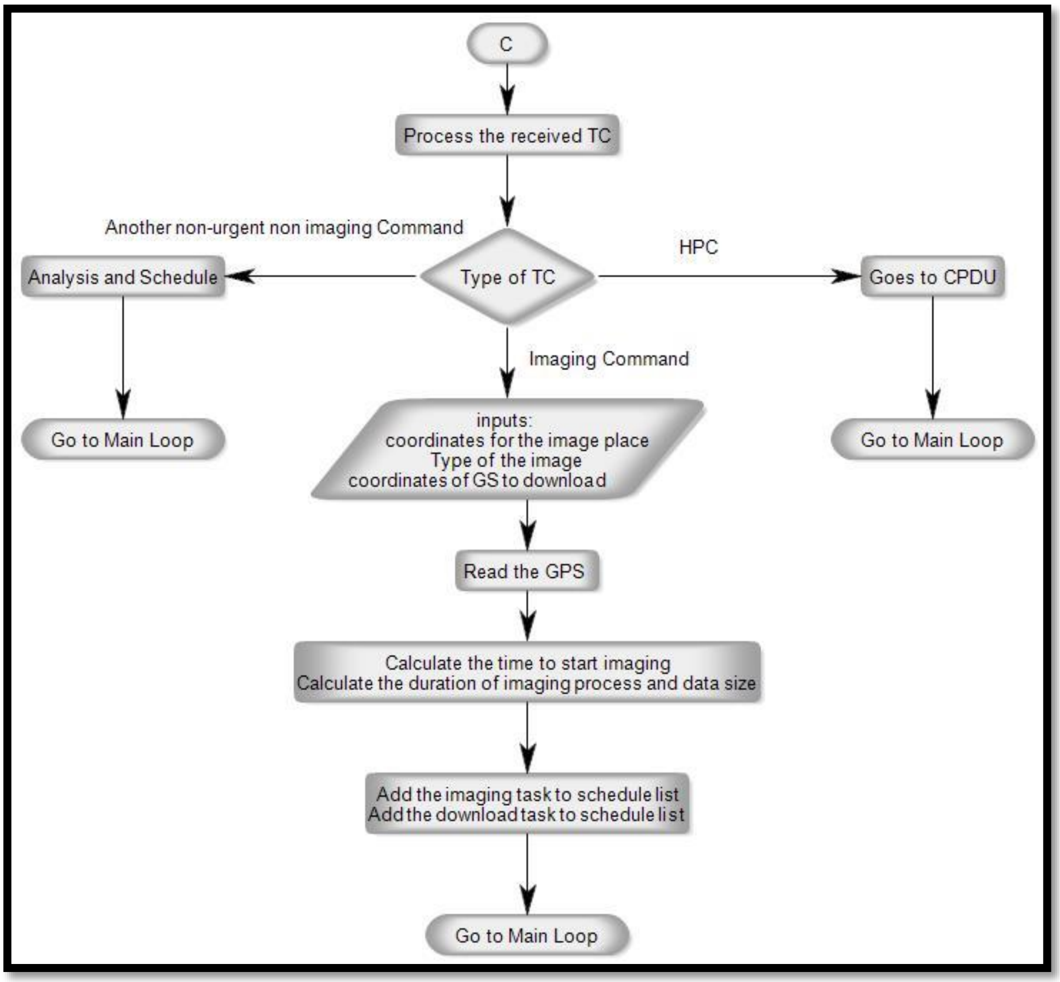

Figure 5.8: The Response to a TC Flow Chart

Figure 5.9 shows the flow chart of the software part that will run if the satellite going to perform imaging task.

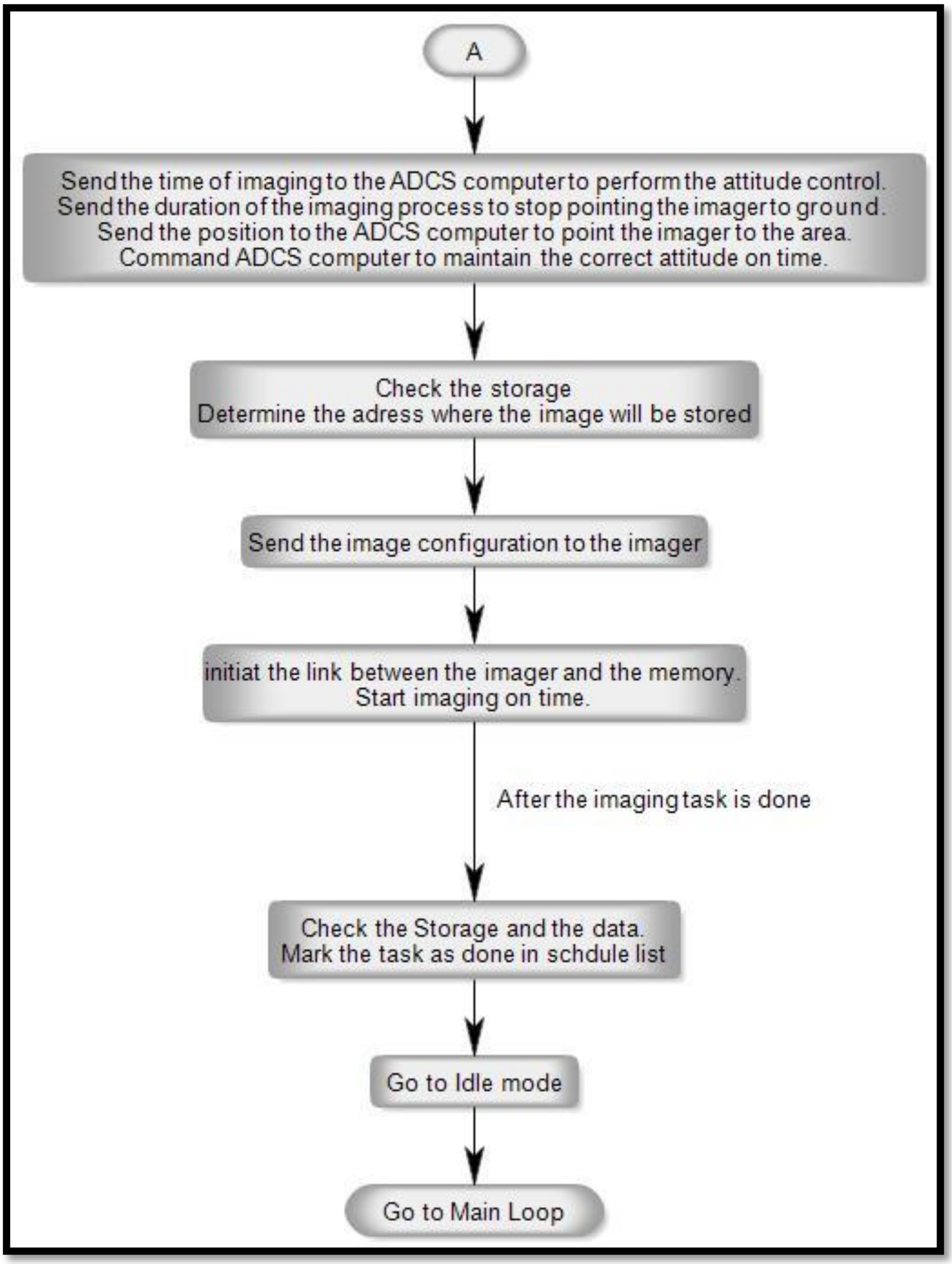

Figure 5.9: The Imaging Task Flow Chart

Figure 5.10 shows the flow chart of the software part that will run if the satellite going to transfer data to a GS.

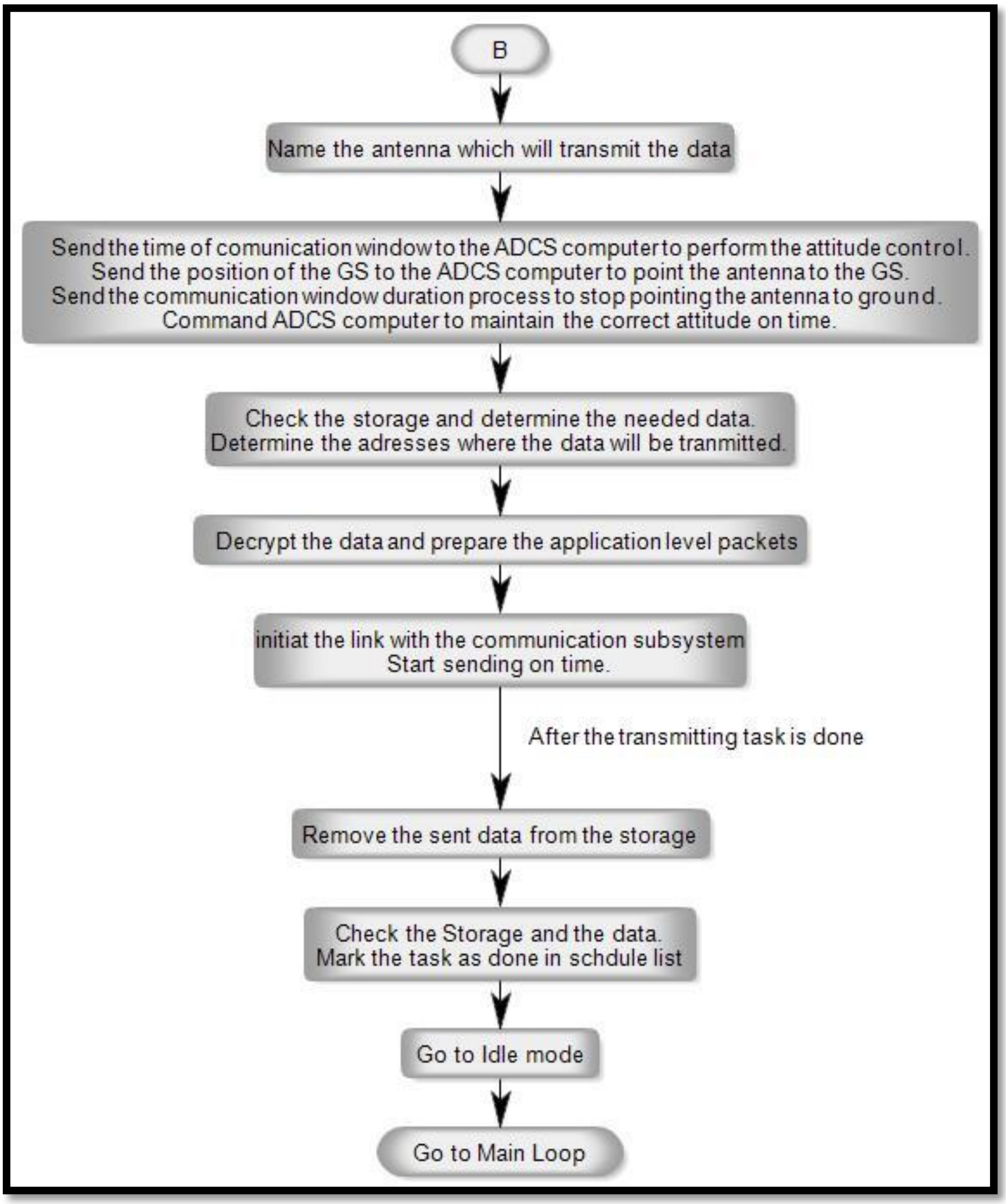

Figure 5.10: Data Transfer Flow Chart

5.17. Final Design Specification

Coming to the end, Table 5.4 shows the final design parameters of the subsystem.

Table 5.4: The Results of the Design process for the subsystem

Parameter	Value
Default image dimensions	8 km x400 km (High Resolution Strip) 300 km x 2000 km (wide-width mode)
Compression ratio	0.7 lossless
Word size in memory	8 bits
Wide width mode image size	5006.79 MBytes
Wide width mode internal data rate	136.87 Mbps
High Resolution Strip mode image size	2670.29 Mbytes
High Resolution Strip internal data rate	365 Mbps
Data collection capacity per day for Khartoum	29 Gbytes

CONCLUSION

This thesis gives a preliminary mission design of the Sudanese satellite SudaSat-1 which fulfill the requirements of a high resolution optical imaging satellite. The mission design names the orbit type and parameters, it would be in a sun-synchronous orbit with an inclination very close to 98 degrees, the LTAN (Local Time Ascending Node) is designed to be around 10 am. The mission design also names the sensor resolution, the image dimensions and the operation modes. For the Management Subsystem, the mission design has a great influence on it, actually it can be considered as a part of the subsystem design. It gives the basics for everything in the subsystem design. STK tool is used to model the mission of the satellite.

The subsystem level design provides the components involved in the management and control operations as well as the data management operations. The design chooses the processor and storage parts, then calculates the specifications needed in every item. This design relay on the commands from the ground to schedule and manage the abnormal cases.

Future work can be done in optimizing the parameters of the mission, designing a new orbit for future satellites. For the onboard software more detailed requirements could be set, more work could be done to achieve automating the management.

For the purpose of the preliminary design the selection criteria of the components was done based on meeting the requirements and the ability to do their tasks, for future work this can be optimized by providing several alternatives those all meet the minimum criteria then selecting the optimum. The cost calculation is not taken into account in this study, for next step studies this should be included.

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APPENDICES

Appendix A1: The Code of Finding the Inclination for the Orbit

Appendix A1: The Code of Finding The Inclination For The Orbit

```
clc;
clear all;
mu   = 398600.440;     % Earth’s gravitational parameter [km^3/s^2]
Re = 6378;             % Earth radius [km]
J2  = 0.0010826269;     % Second zonal gravity harmonic of the Earth
we = 1.99106e-7;    % Mean motion of the Earth in its orbit around the Sun [rad/s]
% Input
Alt = 250:5:1000;     % Altitude,Low Earth orbit (LEO)
a   = Alt + Re;       % Mean semimajor axis [km]
e   = 0.0;            % Eccentricity
h = a*(1 - e^2);     % [km]
n = (mu./a.^3).^0.5; % Mean motion [s-1]
tol = 1e-10;         % Error tolerance
% Initial guess for the orbital inclination
i0 = 180/pi*acos(-2/3*(h/Re).^2*we./(n*J2));
err = 1e1;
while(err >= tol )
   % J2 perturbed mean motion
   np  = n.*(1 + 1.5*J2*(Re./h).^2.*(1 - e^2)^0.5.*(1 - 3/2*sind(i0).^2));
   i = 180/pi*acos(-2/3*(h/Re).^2*we./(np*J2));
   err = abs(i - i0);
   i0 = i;
end
plot(Alt,i,'.b');
grid on;hold on;
xlabel('Altitude,Low Earth orbit (LEO)');
ylabel('Mean orbital inclination');
title('Sun-Synchronous Circular Orbit,Inclination vs Altitude(LEO,J2 perturbed)');
hold off;
for count = 1:100
if Alt(count)==650
   i(count)

end
```

By SMALLSAT IN SPACE FLIGHT/ORBITAL MECHANICS ON APRIL 11, 2013, with modifications.

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